Final Programmatic Environmental Impact Statement

Fish Culture in Floating Net-Pens

Washington Department of Fisheries

Technical Appendices

January 1990

SCHOLZ

TECHNICAL APPENDICES

PLEASE NOTE:

The following technical appendices are intended to provide additional information on the subject of fish farming. There has been no attempt to include information on all facets of fish farming, nor has there been any attempt to evaluate the information presented here. A determination has not been made concerning the applicability of the information to the situation in Washington. Several comments on the Draft EIS requested additional information on fish farming. When possible, the requested information was included in the appendices. The purpose of these appendices is solely to provide information to aid in the ongoing discussion of the fish farming industry. In addition to the appendices, a list of sources of recent information on fish farming is included on the following page. The following is a list of the titles of the appendices:

A	Assessment and Prediction of the Effects of Salmon Fish Farm Culture on the Benthic Community
B	Modeling of Particulate Deposition Under Salmon Fish Farms
C	Phytoplankton and Nutrient Studies Near Salmon Fish Farms at Squaxin Island, Washington
D	Infectious Diseases of Salmon in the Pacific Northwest
E	The Economics of Salmon Farming
F	Permits That May Be Required for Aquaculture Projects
G	Viral Hemorrhagic Septicemia
H	Norwegian and British Columbia Information
I	Land-Based Tank Farms
J	Legislation Authorizing the EIS
K	Effect of Fish Farms on Surrounding Property Values
L	Economic Aspects of Salmon Aquaculture

NOTE: Appendices A and E were completed under separate contracts with the Department of Fisheries.

ADDITIONAL REFERENCES

Further information on fish farming can be obtained from the following sources:

Alaska Finfish Farming Task Force. 1989. Report to the Alaska legislature, draft for public comment. 26p.

B.C. Ministry of Environment. 1988. Environmental monitoring program for fish farms. Prepared by Waste Management Branch and Water Management Branch, British Columbia Ministry of Environment. 77p.

B.C. Ministry of Environment. 1989. Environmental procedures and guidelines for marine fish farms. Draft report. 41p.

Institute of Aquaculture, University of Stirling. 1988. The reduction of the impact of fish farming on the natural marine environment. Prepared for the Nature Conservancy Council: Scottish Headquarters: Edinburgh. 167p.

Institute for Environmental Studies, University of Washington. 1989. Focus on aquaculture. The Northwest Environmental Journal. Vol. 5, No. 1.

International Council for the Exploration of the Sea. 1988. Cooperative research report no. 154. Report of the ad hoc study group on "environmental impact of mariculture." Copenhagen, Denmark. 83p.

Nature Conservancy Council. 1989. Fishfarming and the safeguard of the natural marine environment of Scotland. Nature Conservancy Council: Scottish Headquarters, Edinburgh. 136p.

Standing Committee on Fisheries and Oceans. 1988. Aquaculture in Canada. Report to the House of Commons. 129p.

APPENDIX A

ASSESSMENT AND PREDICTION OF THE EFFECTS OF SALMON FISH FARM CULTURE ON THE BENTHIC COMMUNITY

ASSESSMENT AND PREDICTION OF THE EFFECTS OF SALMON NET-PEN CULTURE ON THE BENTHIC ENVIRONMENT

by

Donald P. Weston, Ph.D.

School of Oceanography, WB-10
University of Washington
Seattle, WA 98195

and

Richard J. Gowen, Ph.D.

Scottish Marine Biological Association
Dunstaffnage Marine Research Laboratory
PO Box 3
Oban, Argyll PA34 4AD
Scotland

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- The farm operators provided feed rate and production information required for the analyses. The Squaxin Island Tribe was particularly helpful by providing boats and operators on several occasions. This work would not have been possible without the cooperation and assistance of tribal staff.

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ABSTRACT

Sediment chemistry and macrofaunal communities were examined in the vicinity of two salmon mariculture facilities in Puget Sound. The Clam Bay farm is a relatively large operation containing 200 to 400 tons of salmon, and has been in operation for about 13 years. Deposition of feed and feces beneath the pens has created an area characterized by high levels of organic carbon and nitrogen and depressed sediment reduction-oxidation potentials. This area extends under the pens and out to a distance of 15 to 60 m from the farm perimeter. The macrofaunal community shows dramatic alterations in this area including the disappearance of most species characteristic of the natural community and high abundances of nematodes and an opportunistic polychaete. More moderate changes in the infaunal community extend at least 150 m from the farm.

The Squaxin Island farm is a comparatively small facility (20 to 40 tons of fish on site) and has been operating only since early 1987. Unlike the Clam Bay site, there was little effect of the farm on sediment chemistry, even directly under the pens. The infaunal community shows evidence of disturbance in an area extending from the pen perimeter out to a distance of 6 m. Within this zone the community appears to have been undergoing gradual change over the 18 months of farm operation.

On the basis of these investigations, macrofaunal community composition appears to be a more sensitive indicator of benthic impacts than measurement of sediment chemical parameters alone. Among the sediment parameters evaluated, redox potential appears to be a valuable tool for rapid and cost-effective impact assessment, at least in coarse-grained sediments.

A model which predicts dispersion of feed and feces from a farm site was tested for agreement with actual conditions at the Clam Bay and Squaxin sites. The model was found to be reliable to within a factor of two or less in predicting the magnitude of organic loading to the seafloor. At the Clam Bay site and, to a lesser extent, at Squaxin Island the areas which the model predicted to receive the greatest input of feed and feces were the same areas showing the highest degree of sediment enrichment. On a broader scale, the model appeared reliable in identifying the areal extent of impact from net-pen culture. After tests at eight farms the model has predicted enhanced carbon fluxes up to 70 m (and usually less than 30 m) from the pen perimeter. These predictions are consistent with the results from this study and other investigations. The model is useful in identifying sites that would be clearly unsuitable for culture or others where environmental impacts are likely to be negligable. There are, however both inherent unknowns and oversimplifying assumptions in the model, which should be recognized to avoid indiscriminant application of the

model and misinterpretation of the results. The data base of current velocity and direction on which model predictions are based is rarely, if ever, available for siting decisions, but would be valuable both to environmental managers and farm operators.

ASSESSMENT AND PREDICTION OF THE EFFECTS OF SALMON NET-PEN CULTURE ON THE BENTHIC ENVIRONMENT

INTRODUCTION

Cultivation of salmon in estuaries and coastal embayments generates substantial quantities of particulate organic wastes consisting principally of feces and uningested feed. It has been estimated that the production of 1 kg of salmon generates 0.5 to 0.7 kg of particulate waste (Weston, 1986; Gowen and Bradbury, 1987). For large farms, which produce several hundred tons of salmon annually, the quantity of particulate waste settling to the seafloor is considerable. Accumulation of organic waste on the sea bed has been found to alter some aspects of sediment chemistry and benthic macrofaunal community composition in the vicinity of salmonid culture operations. The changes in sediment chemistry include increases in carbon, nitrogen and phosphate content (Hall and Holby, 1986), depression in sediment reduction-oxidation potentials (Brown et al., 1987), and changes in the rates of nutrient cycling (Kaspar et al., 1988). Shifts in the species composition and relative abundances of benthic macrofauna have been reported, occasionally with an azoic zone directly beneath the farm (Pease, 1977; Brown et al., 1987). Waste accumulation on the seafloor can have implications for the viability of the farm itself. The release of hydrogen sulfide from anoxic sediments and/or related changes in water quality can adversely effect the health of the cultured fish (Arizono, 1979) and has been the reason for the closure of some operations (Braaten et al., 1983).

At the present time there is a rapid growth in the farming of salmon. The results of this growth will be the expansion of existing farms, some to an annual production of 2,000 to 3,000 tons, and the establishment of multiple farms in individual embayments. As development proceeds potential pollution problems require careful scrutiny, and it has recently been stated that there is a need for models which can be used to predict ecological impact before establishment of a farm (Rosenthal et al., 1987). The development of such models, together with an understanding of the effects of organic wastes on the benthos, is essential to ensure that this form of mariculture does not cause broad ecological change. An additional application of such model would be in resource management, to ensure that farming is not conducted in areas which, through ecological change, can not sustain the long-term use of the site.

This paper describes an assessment of the intensity and spatial extent of impact on the benthos of two farm sites in Puget Sound, Washington. The sites chosen for study differ greatly in physical conditions, farm size and duration of operation, and potentially offer a broad range in the scale of impact. The study was also intended to further test a sedimentation model designed to predict the dispersal of solid wastes from fish farms (Gowen et al, in press). A preliminary test of the model (Gowen et al., 1988), using sediment redox potentials as an indicator of organic pollution, suggested that the model could be used to predict the spatial extent and severity of ecological disturbance of the benthos and in the selection of suitable sites.

MATERIALS AND METHODS

Field sampling and model verification was performed at two salmon net-pen operations in Puget Sound. The Clam Bay farm is a large operation with an annual production of 617 tons and containing 200 to 400 metric tons of salmon at any given time. The farm has been in operation at the same site continuously since the early 1970's. The Squaxin Island farm holds 20 to 30 tons of salmon and has only been in operation since 1987. There are 53 additional pens located 250-500 m south of the Squaxin Island farm. These pens are used to hold juvenile salmon on a seasonal basis, and were largely unused during the period of investigation. Physical characterisics of each site and details of the Clam Bay and Squaxin farms are given in Table 1.

Sampling stations were established at each farm at predetermined distances along 3 transect lines extending out from the pens, varying in length from 30 to 165 m (Figure 1). Field activities included deployment of current meters and sediment traps, collection of sediments for chemistry and grain size analysis, measurement of dissolved oxygen in near-bottom waters, and sampling of benthic macrofauna.

<u>Current measurements</u> - Two Aanderaa current meters were deployed at each of the farm sites, and set to record at 15 minute intervals for a period of 60 days. The meters were placed 2.5 and 5.5 m above the seafloor at the Squaxin Island and Clam Bay sites, respectively.

<u>Sediment traps</u> - Sediment traps were constructed of PVC piping, 15 cm in diameter and 45 cm in length. An array of three traps were placed under the pens and at each station along transects CB1 and SQ1. The distances between the sea bed and the mouths of the traps were 0.5 and 5.5 m at the Squaxin and Clam Bay sites, respectively. Prior to deployment 250 g

Table 1
Physical characteristics of the farms
and surrounding environments

PARAMETER	CLAM BAY	SQUAXIN ISLAND
Depth of water (m at mean lower low water)	10 - 26	4.7 - 5.0
Distance between bottom of pens and sea bed (m at mean lower low water)	6 - 22	1.7 - 2.0
Area of cages (m^2)	14,560	1,184
Duration of operation (years)	13	1.5
Biomass held on farm (metric tons)	200 - 400	20 - 30
Feed provided ($kg \cdot day^{-1}$)	2200 - 5900	400 - 600

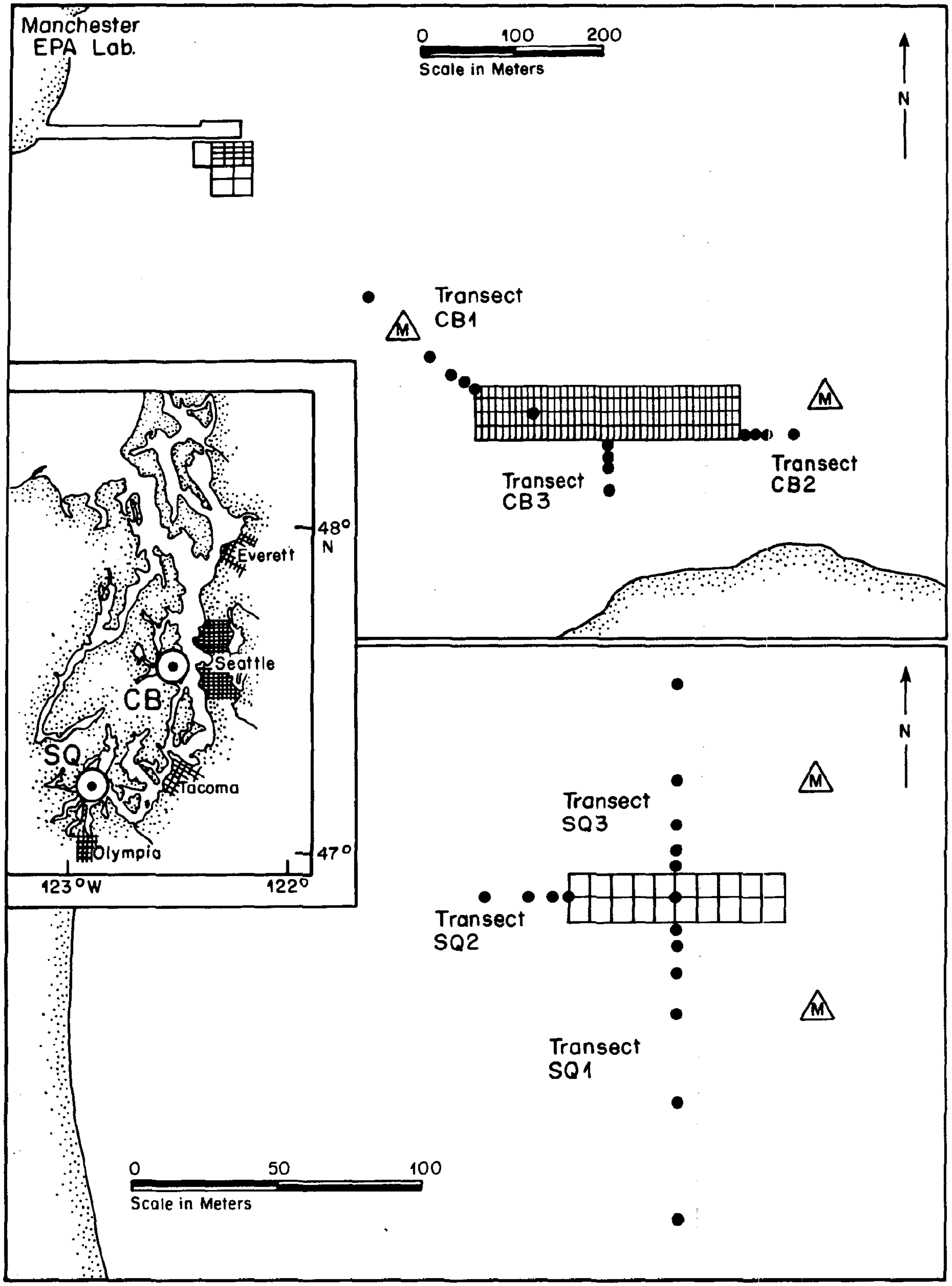


Figure 1. Locations of the two Puget Sound farm sites investigated. Sampling stations are indicated by dots under the pens and along three transects at each site. Locations of the Aanderaa current meters indicated by M symbol.

of reagent grade salt was added to each trap to retard microbial activity and reduce loss of material by resuspension. The traps were deployed for 9 days at the Clam Bay site and 15 days at Squaxin Island. Mercuric chloride was added to the traps at the time of recovery to inhibit microbial activity prior to analysis. The total amount of particulate material retained in the traps was estimated by filtering duplicate aliquots of the homogenized trap contents on to combusted and preweighed 45 um silver filters. The material retained on the filters was analyzed for carbon and nitrogen in a Carlo Erba Model 1106 CHN microanalyzer following vapor phase acidification to remove inorganic carbon (Hedges and Stern, 1984).

Sediment sampling - The upper 1 cm sediment stratum was collected by SCUBA diver (Clam Bay) or Van Veen grab (Squaxin Island). The sediment was analyzed for carbon and nitrogen content in the same manner as the sediment trap material, except that a Perkin Elmer 240 elemental analyzer was used. Sediment redox potentials were measured in diver-collected cores following the method of Pearson and Stanley (1979). Grain size analysis was performed by dry sieving followed by pipette analysis of the silt and clay fraction.

Dissolved oxygen - Near-bottom water samples were collected 5 to 10 cm above the sediment-water interface by SCUBA divers, and analyzed by the Winkler titration method (Strickland and Parsons, 1972).

Benthic macrofauna - Macrofauna samples were collected at each farm site in connection with independent investigations. The Squaxin samples were collected as part of the operator's routine monitoring program which was scheduled so as to sample concurrently with the present investigation. The Clam Bay samples were collected as part of an EPA-funded study by the University of Washington to examine the effects of organic enrichment on benthic communities (Weston, 1988).

At the Squaxin Island farm macrofaunal samples were collected at each station along transect SQ1. Three 0.008-m^2 cores were collected by diver at each station. The contents of two of the cores were washed on a 1.0-mm screen, while the third core was washed on stacked 0.5 and 1.0-mm screens. The Clam Bay macrofauna samples were collected one year prior to the present investigations at stations closely approximating those of transect CB1. Three samples were collected at each station using a 0.06-m^2 spade corer, and washed on a 0.5 mm screen sieve.

The predicted dispersal of feed and feces from the net-pens was determined using the sedimentation model of Gowen et al. (in press). The model uses a value of 4 $cm \cdot sec^{-1}$ for the settling velocity of feces (Warrer-Hansen, 1982), and a settling velocity for uneaten feed that was determined in a settling column using feed from the specific farm. The area occupied by the farm was divided into a grid of 1 m squares, and waste production was assumed to be evenly distributed over the farm area. Solid waste production (in units of g organic carbon$\cdot m^{-2} \cdot hr^{-1}$) was calculated as a proportion of the feed provided. The amount of waste feed was assumed to be 15%, although the actual wastage varies greatly among farms and is generally unquantified (see p. 54 for complete discussion). The fecal production was estimated to be 30% of the ingested feed (Penczak et al., 1982). Hourly values of current velocity and direction were used to calculate the horizontal displacement of feed and feces in each array element using the equations:

$$I + \frac{(D) \times (V \cos \emptyset)}{U}$$

$$J + \frac{(D) \times (V \sin Ø)}{U}$$

where I and J are the co-ordinates of the waste within the array at the start of each hour. D (water depth under pens) divided by U (settling velocity of feed and feces) determines the time during which horizontal displacement takes place. V cos Ø and V sin Ø provide the components of the horizontal displacement of a particle. Thus, the above equations give the X and Y co-ordinates of a particle on the sea bed in relation to the position of the farm at the end of each hour. The model was run using current data over one or more spring-neap tidal cycles and integrated the dispersal and input of organic carbon waste over this time period.

RESULTS

CLAM BAY SITE

Fourteen stations were sampled in the vicinity of the Clam Bay farm site, ranging from directly under the net-pens to a distance of 165 m from the perimeter of the complex (Table 2). The bottom topography at the farm site was steeply sloped, with water depths increasing to the north and east. Water depths near the southwest corner of the cage complex were 10 m at MLLW in comparison to 26 m at the northeast corner. Sampling in the deeper areas was not possible by SCUBA diving, thus all samples were collected at depths of 19 m or less. Seawater temperature and salinity of near bottom waters were 13^{o}C and 30 ppt, respectively.

Sediments were primarily medium sands (0.25 - 0.5 mm diameter) to the east and south of the pen complex with finer sands (0.125 - 0.25 mm) to the northwest. Silts and clays comprised less than 5% of the sediment throughout the study area. Shell and gravel comprised a large fraction of the sediment (19%) only at stations to the east of the farm site.

Water Currents

Two current meters were deployed near the Clam Bay farm site. The first was positioned 100 m east of the net-pen complex, 5.5 m above the seafloor and 23.5 to 27 m below the surface (depending on tidal stage). The second was located 100 m northwest of the farm, 5.5 m above the seafloor and 9.5 to 13 m below the surface. Data collected during the period July 6 through August 4, 1988 were analyzed and presented in Figure 2. The current regimes showed pronounced differences at the two sites as a result of either depth-related differences in current flow, or, more probably, local variations attributable to the close proximity and curvature of the shoreline.

Table 2
Clam Bay station summary

Station or Transect	Distance from net-pens (m)	Water depth (m at MLLW)	Substrate
A	0	15	
Transect CB1			
	0	16	
	15	16	
	30	16	
	60	15	
	165	15	0.3% shell/gravel 95.7% sand 4.0% silt and clay
Transect CB2			
	0	13	
	15	14	
	30	15	
	60	19	19.4% shell/gravel 77.1% sand 3.5% silt and clay
Transect CB3			
	0	13	
	15	12	
	30	11	1.8% shell/gravel 98.2% sand 0% silt and clay
	60	10	

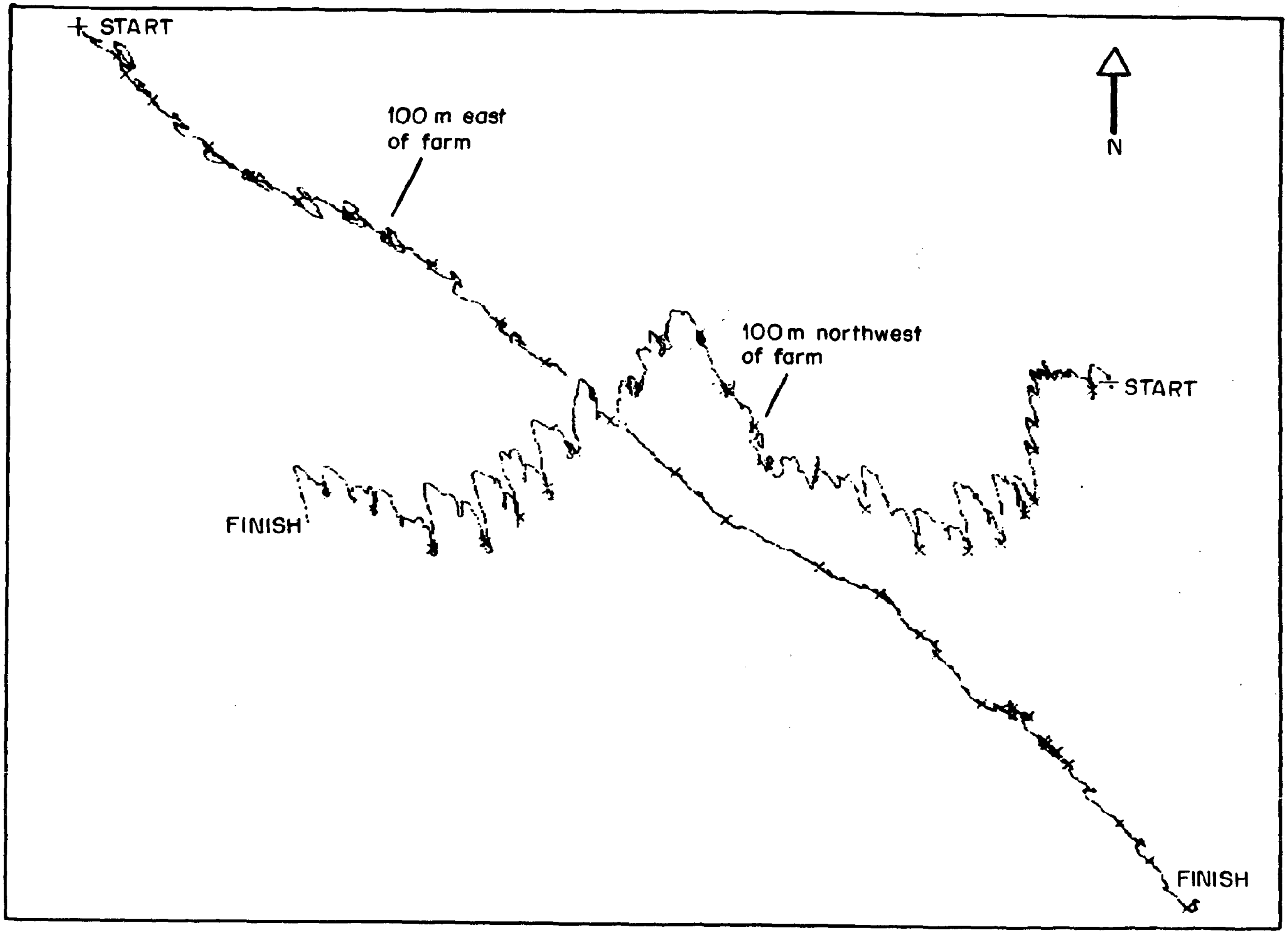


Figure 2. Progressive vector diagrams based on the two current meter records from the Clam Bay site. X symbols indicate 24-hour intervals.

The current data are presented in the form of progressive vector diagrams. These diagrams were created by drawing a vector for each of the 690 current observations such that the oreintation of the vector corresponds to the direction of the current and the vector's length corresponds to current velocity. The vectors are then arranged in a head-to-tail fashion with "start" and "finish" indicating the first and last records, respectively. East of the farm site (Figure 2) most of the vectors were oriented to the southeast, indicating current flows primarily in this direction with little evidence of tidal oscillation. The constancy factor at this site was 94.7%. (A constancy factor of 100% would indicate currents consistently in one direction; a constancy factor of 0% would indicate that currents flowed in all directions with equal frequency). The mean current velocity over the period of observation was 9 $cm \cdot sec^{-1}$, although velocities as high as 36 $cm \cdot sec^{-1}$ were recorded. These current data were collected to model the dispersal of solid wastes sinking from the pens, so the measurements were taken at a depth of about 25 m. Current velocities at the depth of the net-pens (0-4 m) are likely to be somewhat different.

Northwest of the farm site there was a strong tidal influence with currents flowing alternately to the northwest and to the south. The net current flow was to the west with a relatively low constancy factor of 65.6%. Current velocities were slightly lower than those recorded by the other meter. Mean velocity was 6 $cm \cdot sec^{-1}$ with a maximum of 31 $cm \cdot sec^{-1}$.

Sediment chemistry

Total organic carbon and total nitrogen in surficial sediments exhibited similar patterns of enrichment throughout the study area (Figures 3 and 4). The highest levels of enrichment were found under the southern perimeter of the farm site (CB3-0 m) and 15 m east of the site (CB2-15 m). To the east of the farm site (CB2) the area of enrichment extended to

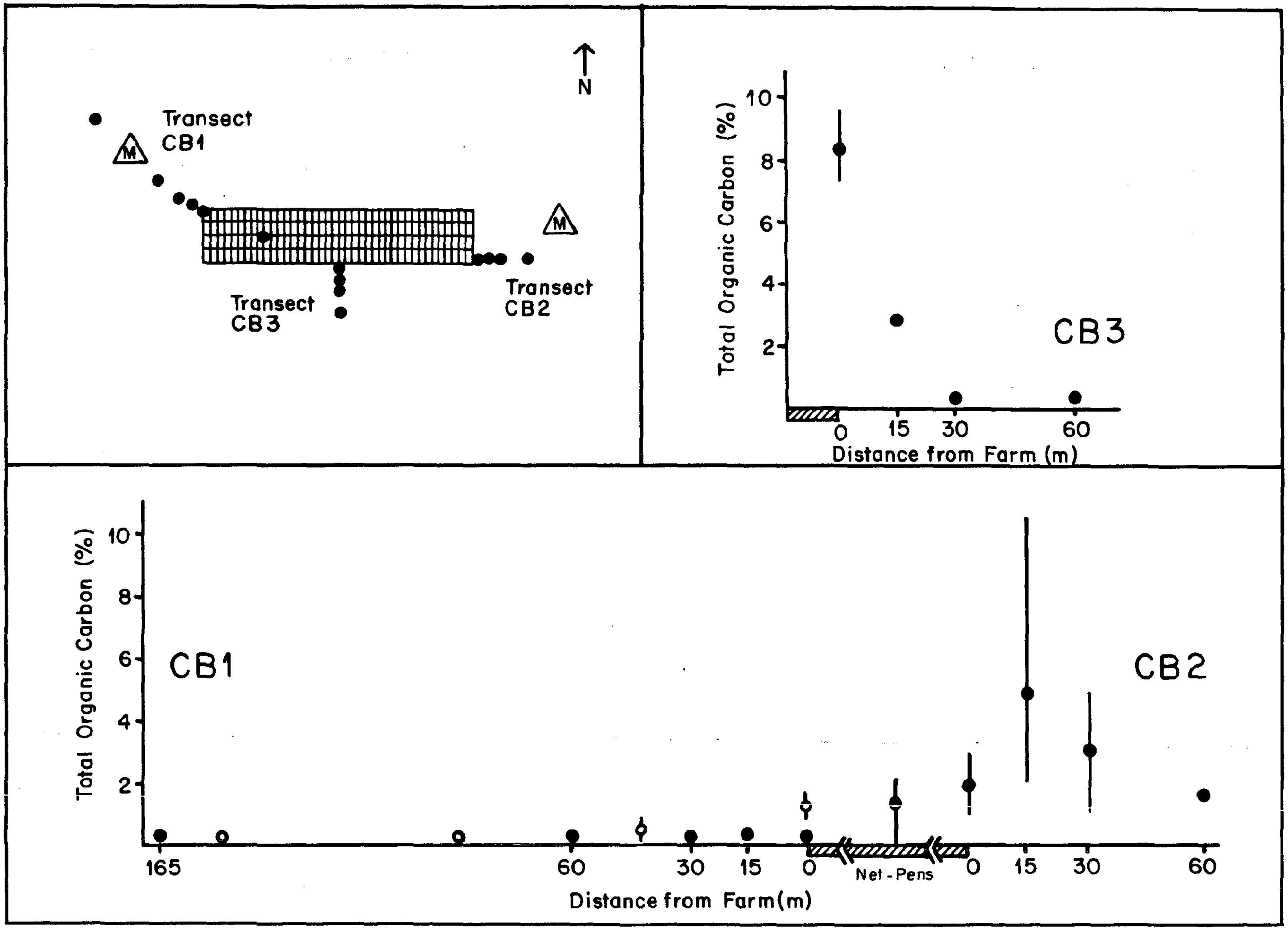


Figure 3. Total organic carbon concentrations in sediments surrounding the Clam Bay farm. Range bars are not shown if less than the size of the mean symbol. Open circles show data collected one year earlier as part of a separate investigation.

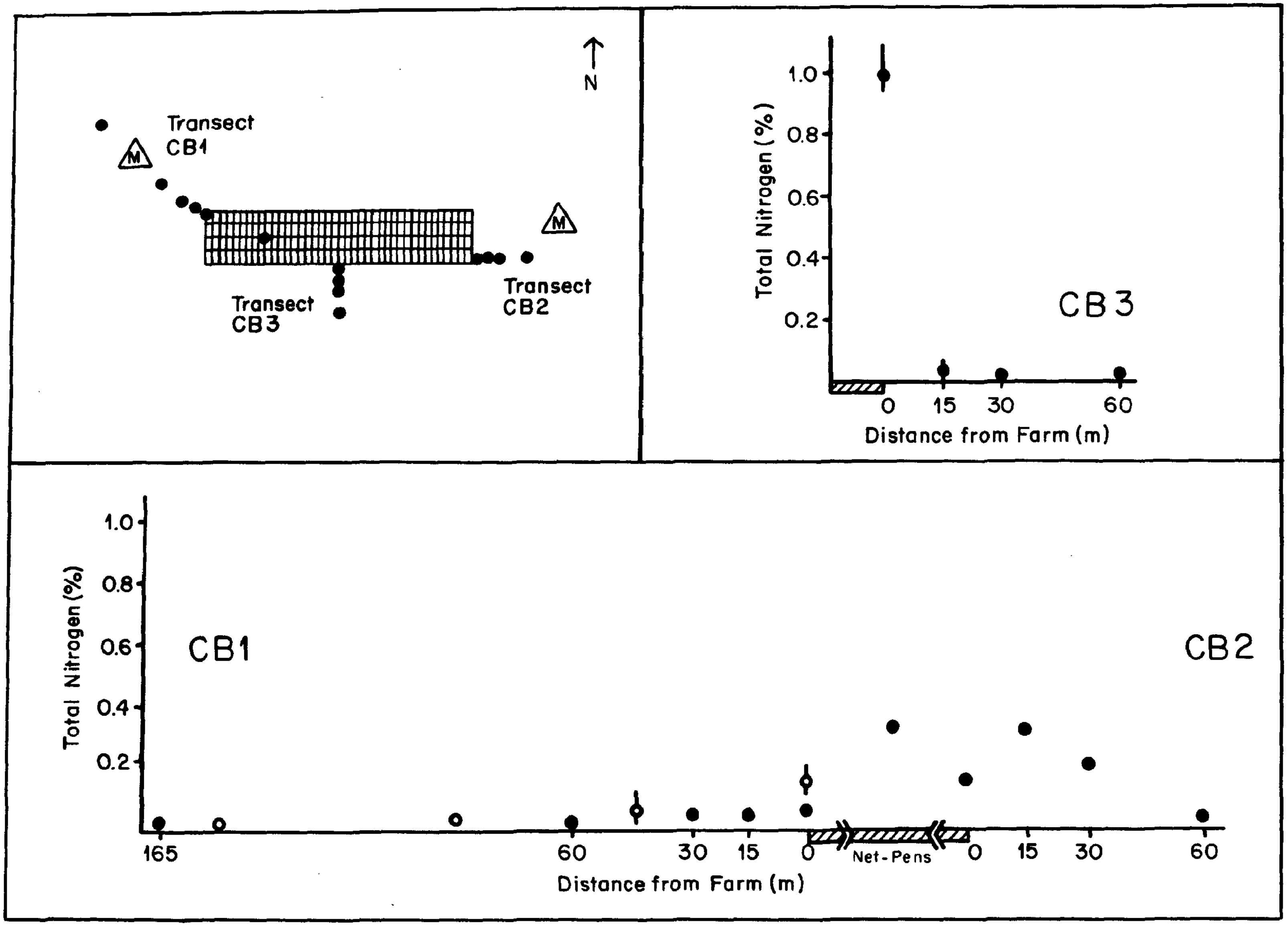


Figure 4. Total nitrogen concentrations in sediments surrounding the Clam Bay farm. Range bars are not shown if less than the size of the mean symbol. Open circles show data collected one year earlier as part of a separate investigation.

a distance of at least 30 m (nitrogen) to 60 m (carbon). To the south enrichment was limited to within 15 m of the net-pens. Northwest of the farm nitrogen showed a statistically significant enrichment to a distance of 30 m (Kolmogorov-Smirnov two-sample test among all possible sample pairs, $\alpha < 0.05$), but carbon levels remained uniformly low throughout the transect. The area northwest of the net-pens had also been sampled in July 1987 as part of an independent study (Weston, 1988). The results of the current sampling were generally similar to the results from the previous year except in close proximity to the net-pens. Within 45 m of the farm carbon and nitrogen concentrations were substantially reduced relative to their levels one year earlier. This reduction is not due to stocking density since the total biomass of fish in the farm was actually 20% greater during the present investigation than one year earlier, but other factors such as small differences in station location or sampling artifacts (diver vs. box corer) may explain this apparent decrease.

The reduction-oxidation potential (E_h) is a quantitative measure of the reducing or oxidizing intensity of sediments. Positive E_h values are generally characteristic of sediments which have a large grain size, are well oxygenated, and/or are poor in organic matter. Negative E_h values are measured in sediments which are rich in organic matter, consist largely of fine sediments, and/or are poorly oxygenated. Sediments receiving high inputs of feed and feces from an aquaculture facility would be expected to have more negative E_h values relative to background conditions assuming grain size is comparable.

At the Clam Bay farm site trends in E_h values closely mirrored gradients in total organic carbon and total nitrogen. Background values were generally about 350 mv at the sediment water interface and 250-300 mv at a depth of 4 cm in the sediment column (Figure 5). With increasing proximity to the pen site, E_h values were reduced throughout the sediment column. The area of depressed potentials extended from 30 m

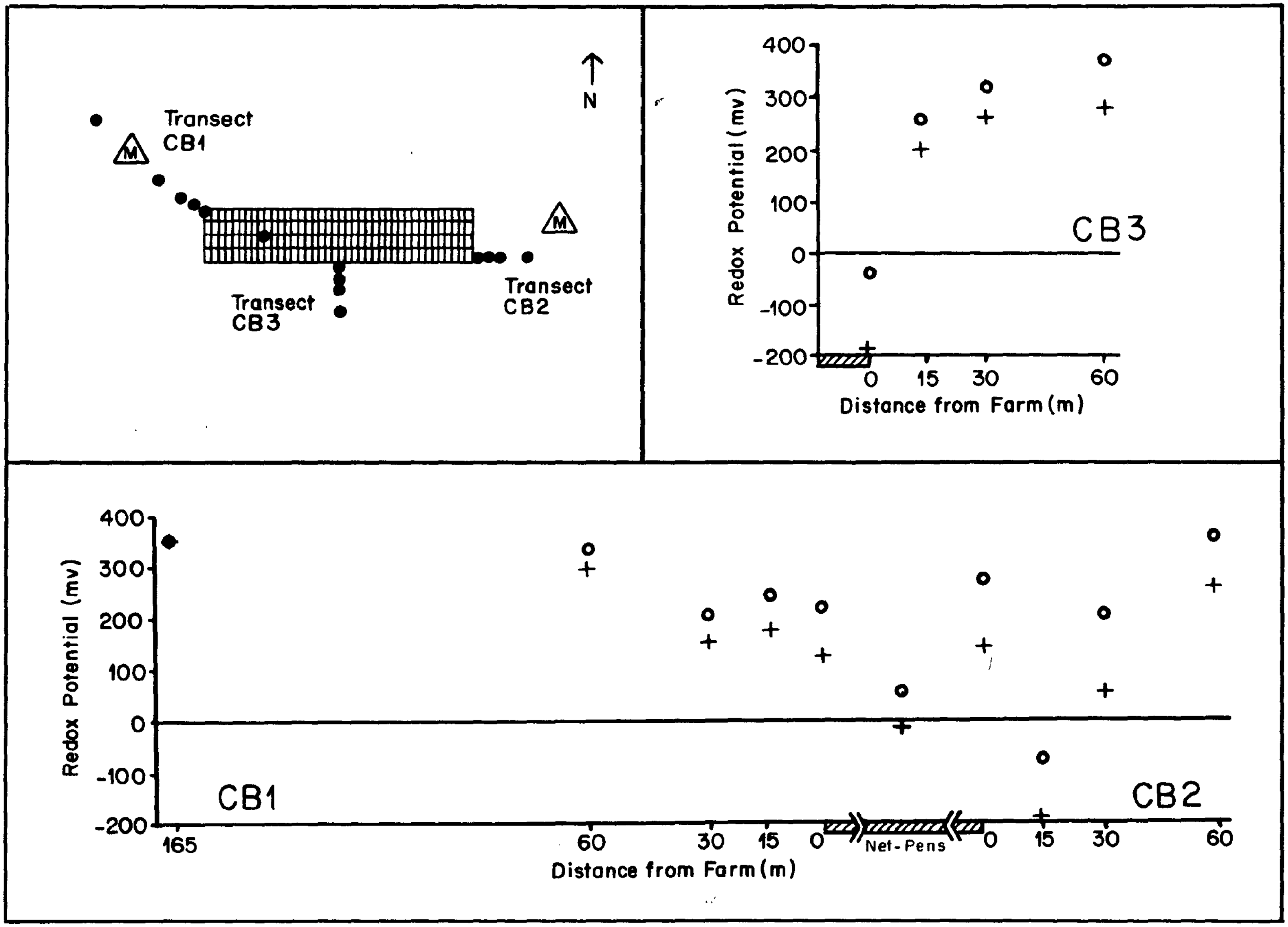


Figure 5. Reduction-oxidation potentials in sediments surrounding the Clam Bay farm. Open circles represent potentials at the sediment-water interface; cross symbols represent potentials at a depth of 4 cm in the sediment.

northwest of the net-pens, to 30 m east of the net-pens, to 15-30 m south. Reducing conditions at the sediment-water interface were evident only 15 m east of the net-cage complex and directly under the southern perimeter.

Dissolved oxygen

Dissolved oxygen concentrations at a height of 5 to 10 cm above the sediment-water interface were uniformly about 8 $mg \cdot l^{-1}$ throughout the study area (Figure 6). The dissolved oxygen sampling design was necessarily less than ideal, since the various stations were sampled over a 6 hr. period and it is not possible to differentiate between upcurrent and down-current sites. Nevertheless the data should show if the enriched sediments caused a dramatic depletion in dissolved oxygen of the overlying water as has been observed elsewhere (Brown et al., 1987). No such depletion was evident, presumably because of the high current velocities of the site.

Sediment traps

Seven sediment trap arrays were deployed along transect CB1, but because of limitations in bottom time and air supply, the divers were only able to retrieve one array directly under the net-pens (Station A) and the array at the farm perimeter (CB1-0 m). Duplicate samples from the three traps within each array were analyzed, resulting in six estimates of deposition rates at each station.

Directly under the net-pens the estimated sedimentation rate was 52.1 kg dry $wt. \cdot m^{-2} \cdot yr^{-1}$ (range of six samples = 46.6 - 55.2). At the pen perimeter the sedimentation rate was 29.7 $kg \cdot m^{-2} \cdot yr^{-1}$ (range 27.8 - 30.8). The particulate material collected directly under the net-pens was approximately twice as enriched in organic carbon as that collected in the trap at the farm perimeter (25.9% and 12.0%, respectively). The

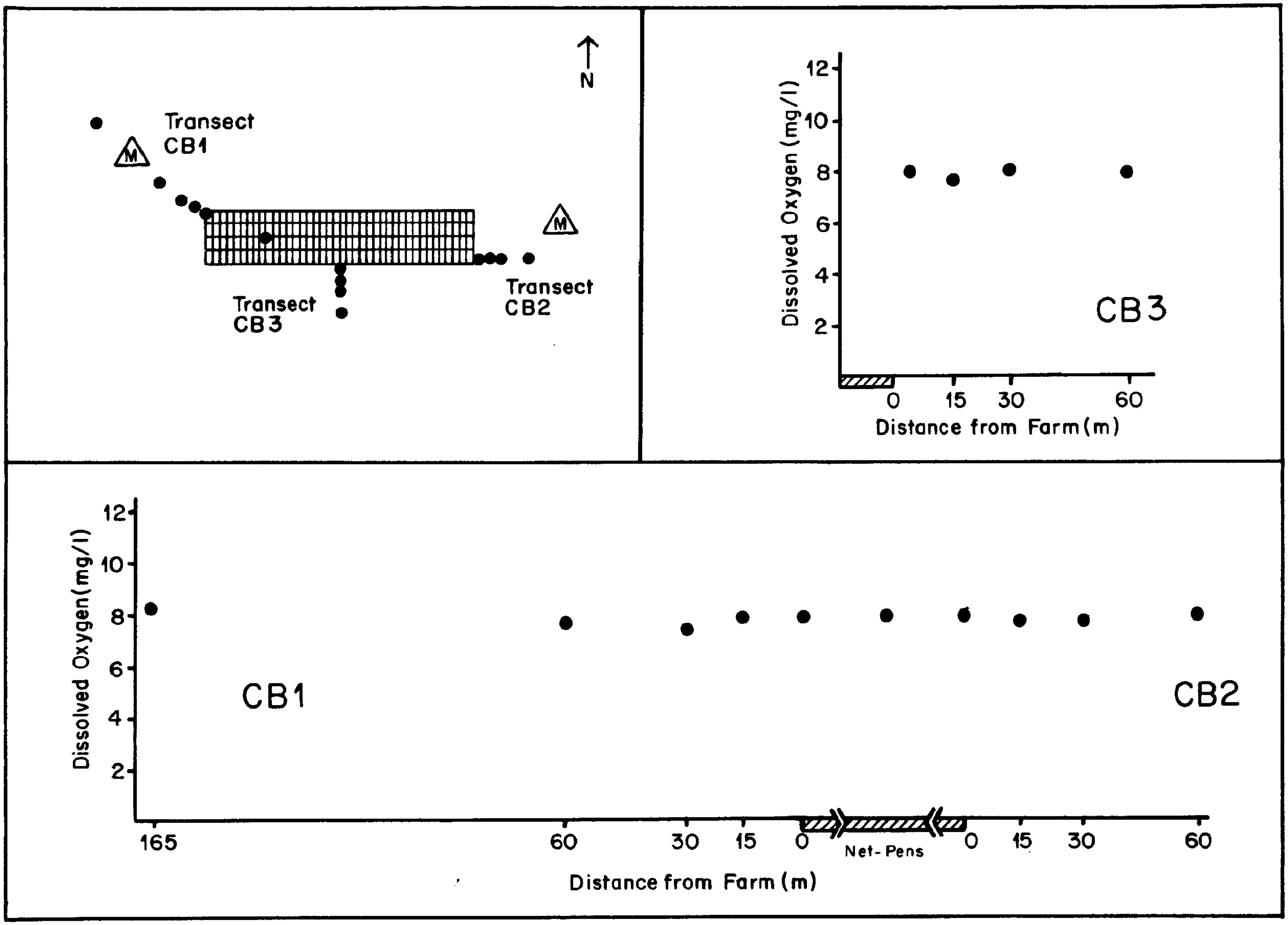


Figure 6. Dissolved oxygen concentrations in near-bottom water surrounding the Clam Bay farm site.

estimated flux of organic carbon to the seafloor was 13.3 kg $C \cdot m^{-2} \cdot yr^{-1}$ under the net-pens and 3.6 kg $C \cdot m^{-2} \cdot yr^{-1}$ at the perimeter.

Macrofauna

Macrofauna were collected one year earlier at four stations along transect CB1 at points close to but not identical to those sampled during the present study (i.e., distances from the farm perimeter of 0, 45, 90, 150 and 450 m vs. 0, 15, 30, 60 and 165 m in the present study). Extensive data analysis is still in progress, so preliminary conclusions are limited to assessment of abundance, biomass, species richness and the density of indicator species.

Figure 7a illustrates typical qualitative changes in species number, biomass and species abundance along a gradient of organic enrichment (Pearson and Rosenberg, 1978). At low levels of organic input, a transition zone develops in which abundance, biomass and species richness gradually decrease from levels typical of the unpolluted environment. In this transition zone there may be a slight species richness and biomass peak attributable to a phenomenon known as "biostimulation". In this area the organic input provides a rich food source, yet the rate of input is not so great that it interferes with the mechanics of suspension feeding nor causes serious oxygen depletion. At a somewhat higher rate of input, total macrofaunal abundance attains a maximum value. Biomass may also be slightly elevated, but the number of species is very low. The increased abundance and biomass results from the proliferation of a few opportunistic species. With still higher rates of organic input there is a complete absence of benthic macrofauna. The rate of organic input is so great that oxygen levels in bottom waters and sediments decrease (or sulfide levels increase) to such an extent that aerobic organisms can not survive.

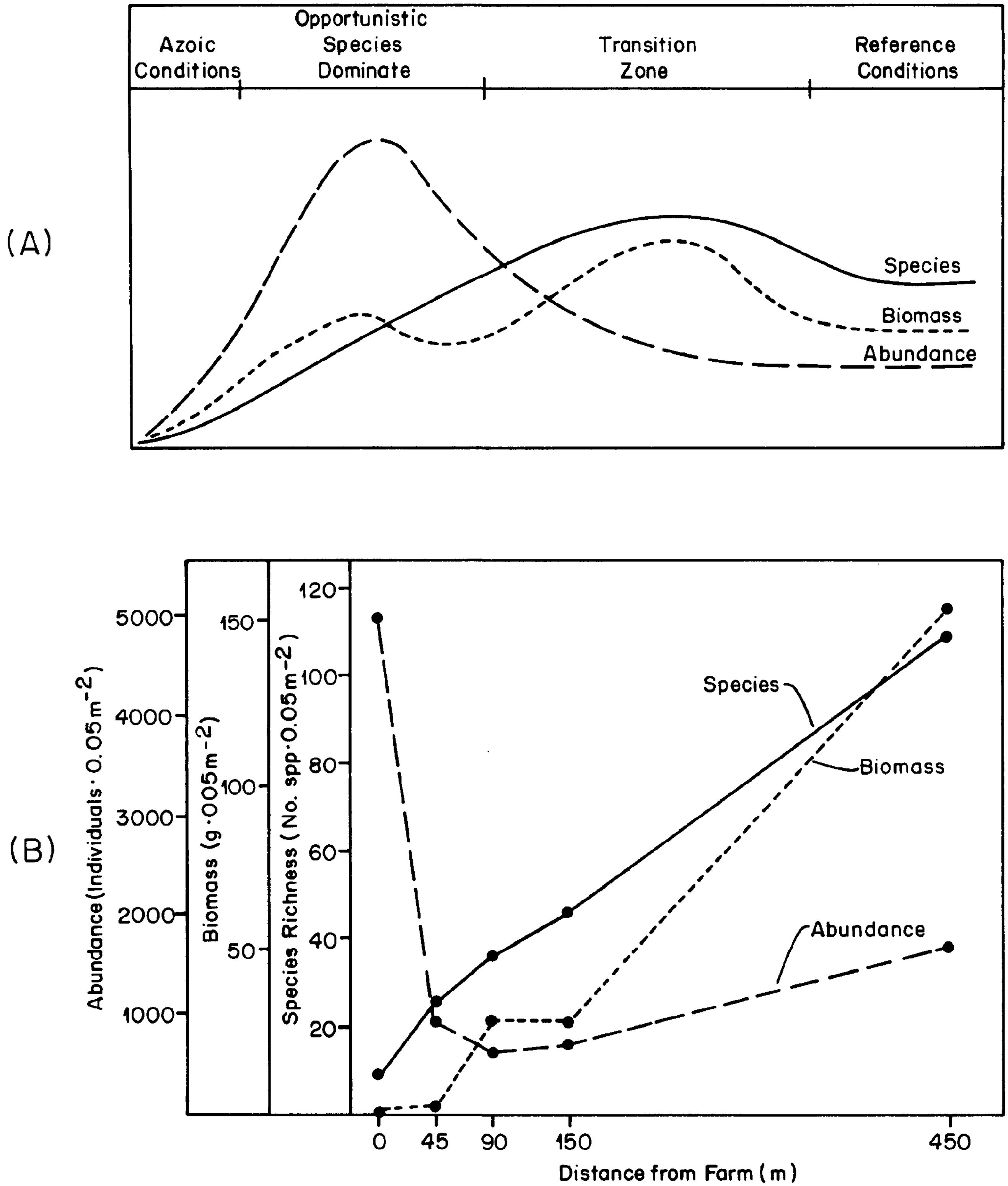


Figure 7. Trends in species richness, biomass and macrofaunal abundance along gradients of organic enrichment. (A) Generalized trends based on Pearson and Rosenberg (1978); (B) Data collected along transect CB1 at the Clam Bay farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

Trends in species number, abundance and biomass are shown along transect CB1 for comparison with the ideal model (Figure 7b). Total macrofaunal abundance was elevated 4-fold at the perimeter of the net-pen complex, and decreased to near background levels within 45 m. This peak in abundance was due almost entirely to the contributions of nematodes and the polychaete _Capitella_ cf. _capitata_. Areal species richness increased consistently along the length of the transect. Biomass was much reduced to a distance of at least 45 m from the pens, for despite the high density of individuals, the organisms were relatively small. Moderate biomass levels were found between 90 and 150 m. The highest biomass was observed at 450 m from the pen site due to the appearance of several large deep-burrowing organisms including bivalves, sipunculans and echiurans.

Capitella cf. _capitata_ is widely recognized as an indicator of organic enrichment and has been found in the vicinity of net-pens throughout the world (Kitamori, 1977; Pease, 1977; Ervik et al., 1985; Brown, 1987). The species was present in densities of over 12,000 indiv.$\cdot m^{-2}$ adjacent to the net-pens, and remained in high densities up to 150 m or more from the farm site (Figure 8).

The macrofaunal data from Clam Bay are generally consistent with the ideal model of changes along an enrichment gradient. No azoic conditions were observed, although no samples were collected directly under the pen complex. The data indicate dramatic community alterations beneath the facility perimeter, including the disappearance of most species characteristic of undisturbed Clam Bay habitats. Moderate disturbance with gradually improving conditions was evident between 45 and 150 m from the farm. Normal conditions were reached at some point between 150 and 450 m from the farm.

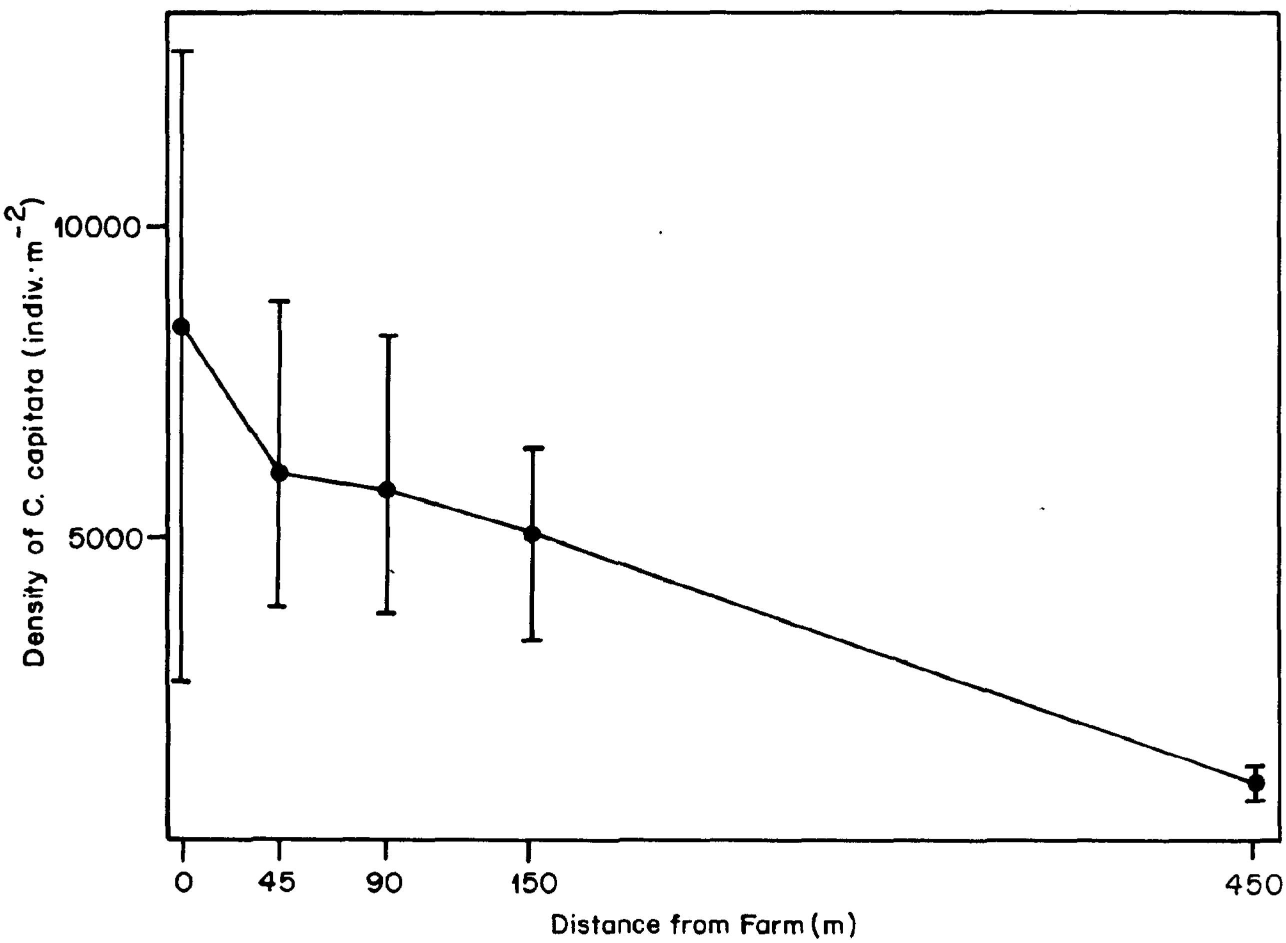


Figure 8. Density of the opportunistic polychaete *Capitella* cf. *capitata* along transect CB1 at the Clam Bay farm site. Vertical bars represent range of the three samples at each station.

Dispersion model

The sedimentation model was run based on the data of Table 3. Standing stock and feeding rate were provided by the farm operator, and based on monthly mean values of these parameters over the previous twelve months. The organic carbon content of the feed was measured directly as was the settling velocity of the feed pellets. Settling velocity of feces was taken from the literature (Warrer-Hanson, 1982). Literature values of feed wastage range from 1 to 30% (VKI, 1976; Penczak, et al., 1982; Braaten, et al., 1983; Gowen, et al., 1985), and lacking a measurement specific to the Clam Bay facility, a wastage of 15% was assumed arbitrarily.

The dispersion model predicted that the area directly under the net-pens would be subject to the greatest rate of solid waste deposition (Figure 9). Areas to the north and west of the farm should recieve very little feed and fecal matter, with the vast majority of the material moving towards the south and east. The area delimited by the 1 kg $C \cdot m^{-2} \cdot yr^{-1}$ isopleth extends 70 m from the farm at its most distant point.

There is extraordinary agreement between the rate of organic carbon flux predicted by the model and that measured in the sediment traps. Directly under the net-pens at the trap location the predicted rate is 11.1 kg $C \cdot m^{-2} \cdot yr^{-1}$, in comparison to the measured rate of 13.3 kg $C \cdot m^{-2} \cdot yr^{-1}$. At the northwest corner of the farm site the predicted and measured rates were 2.5 and 3.6 kg $C \cdot m^{-2} \cdot day^{-1}$, respectively.

The dispersion model predicts a deposition rate, and thus a rigorous test of the model would also require rate measurements, such as those obtained from the sediment traps. In the strict sense, a static measurements such as organic carbon concentration or redox potential can not be used to test the model since no information is available on *in situ* post-depositional processes. Nevertheless, since sediment trap data were so limited, the assumption was made that post-

Table 3
Data used in dispersion model at the Clam Bay farm site

Farm size: 280 m by 52 m with long axis oriented east-west
Depth of pens: 4 m
Standing stock: 352 metric tons
Feeding rate: 4409 kg·day^{-1}
Organic carbon content of feed: 48%
Feed wastage: 15%
Settling velocity of feed: 10 cm·sec^{-1}
Settling velocity of feces: 4 cm·sec^{-1}
Water depth (approx. average of MLLW and MHHW along sampling transects): 18 m
Current data: July 6 - August 4, 1988; meter located 100 m east of farm site.

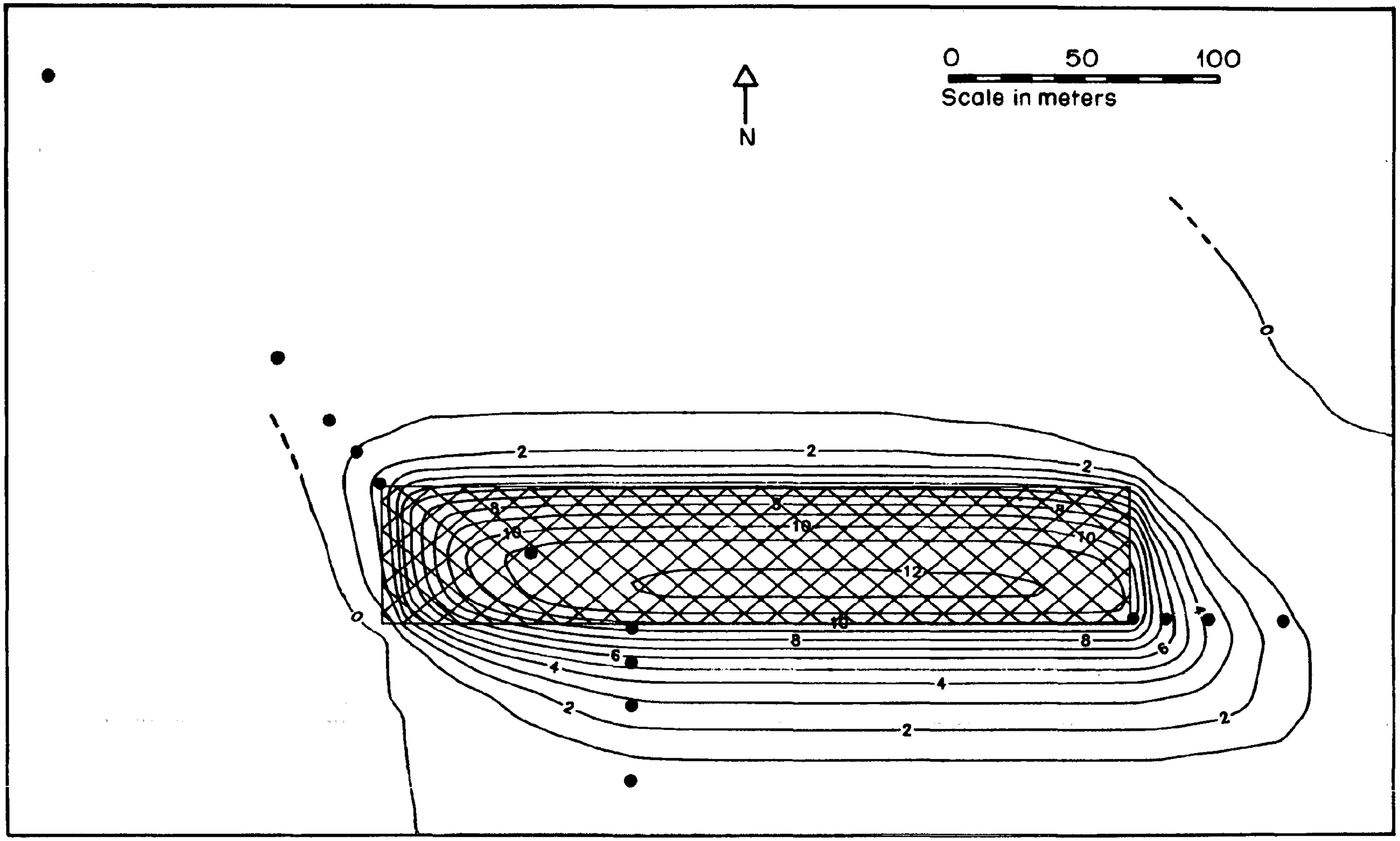


Figure 9. Model predictions of organic carbon loading to the seafloor at the Clam Bay farm site. Contour units are kg $C \cdot m^{-2} \cdot yr^{-1}$. Dots indicate locations of sampling stations used for model verification.

depositonal processes (e.g., mineralization, resuspension) were uniform throughout the study area, and a test was made of the model's ability to identify areas of greatest organic enrichment (Figure 10). There was a significant correlation between predicted deposition rates and measurements of both sediment organic carbon content and redox potential (Spearman rank correlation, $\alpha >> 0.01$). The model, therefore, performed well in identifying those areas surrounding the Clam Bay farm which experienced the greatest degree of organic enrichment.

SQUAXIN ISLAND SITE

Sixteen stations were sampled in the vicinity of the Squaxin Island farm site (Table 4). Water depths in the area were uniformly 5 m at mean lower low water. The bottom of the net-pens were 2 m above the seafloor at this tidal stage and approximately 6.5 m above the seafloor at mean higher high water. Seawater temperatures were approximately 15^{o}C; salinity was 30.5 ppt.

The substrate was principally silt with varying amounts of sand (14 - 30%) and shell fragments (1 - 40%). Shell debris was so dense at some sites that the collection of undisturbed sediment cores was difficult or impossible. There was no visible evidence of culture-related disturbance on the sediment surface (e.g., *Beggiatoa* mats, feed or fecal material).

Water Currents

Current meters were moored 60 m to the south and to the north of the eastern end of the net-pen complex. Both were positioned 2.5 m above the seafloor and 2.5 to 7 m below the surface (depending on tidal stage), and left in place from June 6 to August 5 1988.

Both meters showed strong north-south tidal oscillations,

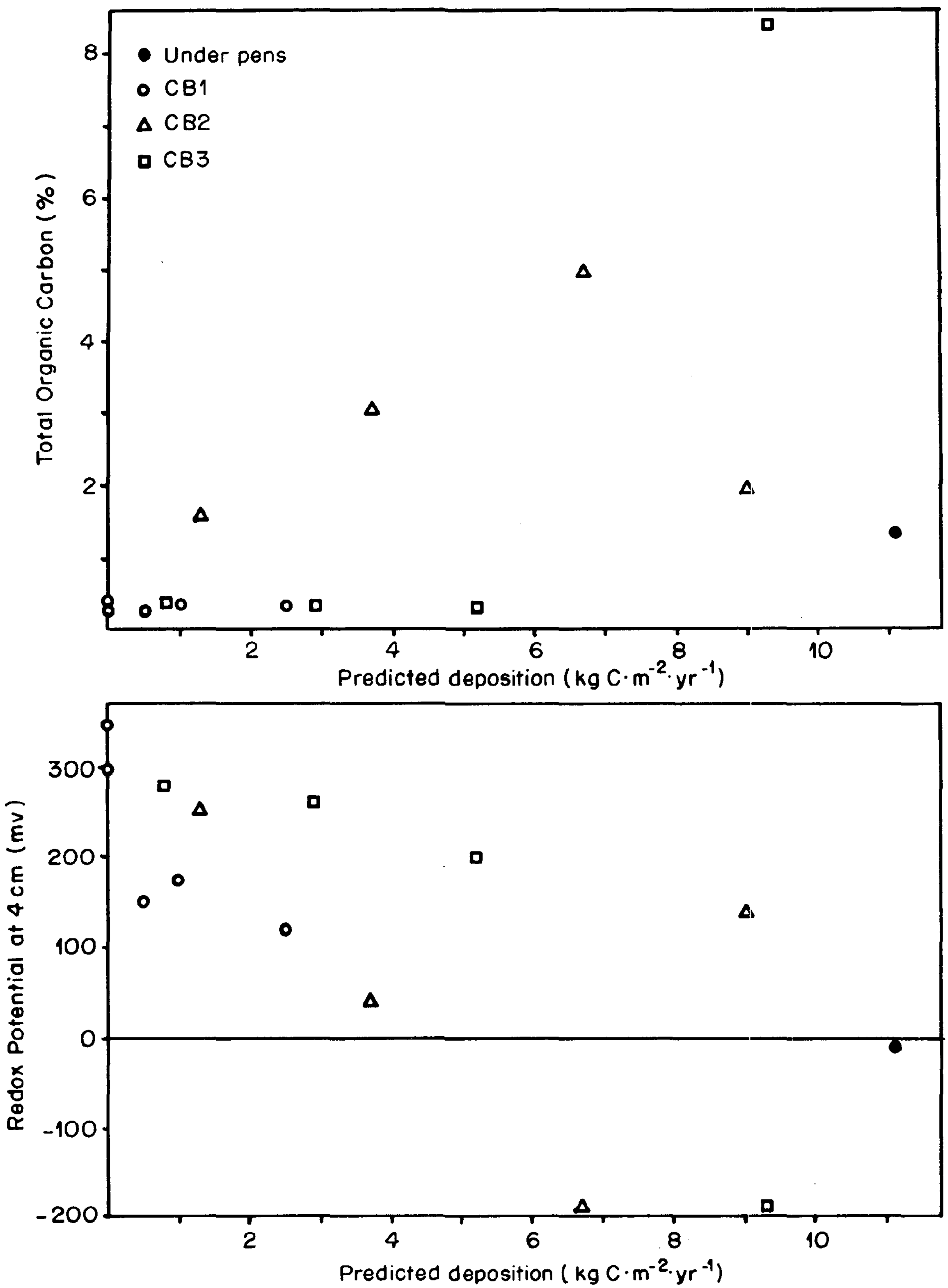


Figure 10. Comparisons of predicted carbon deposition based on the sedimentation model with field measurements of total organic carbon and redox potentials at the Clam Bay farm site.

Table 4
Squaxin Island station summary

Station or Transect	Distance from net-pens (m)	Water depth (m at MLLW)	Substrate
A	0	5	
Transect SQ1			
	0	5	1.1% shell/gravel 14.3% sand 84.6% silt and clay
	6	5	11.2% shell/gravel 13.6% sand 75.2% silt and clay
	15	5	3.1% shell/gravel 16.9% sand 80.0% silt and clay
	30	5	2.8% shell/gravel 18.0% sand 79.2% silt and clay
	60	5	46.4% shell/gravel 32.2% sand 21.4% silt and clay
	100	5	
Transect SQ2			
	0	5	
	6	5	
	15	5	
	30	4	41.2% shell/gravel 29.8% sand 29.0% silt and clay
Transect SQ3			
	0	5	
	6	5	
	15	5	
	30	5	
	60	5	0.4% shell/gravel 17.3% sand 82.3% silt and clay

with the southerly flow predominating (Figure 11). A significant westerly component was evident only in the meter located south of the farm site. The constancy factors were 90.9 and 83.3% for the northern and southern locations, respectively. Current velocities at the northern site averaged 6 $cm \cdot sec^{-1}$ over the 60 day deployment with a maximum recored velocity of 31 $cm \cdot sec^{-1}$. Current velocities of 15 to 18 $cm \cdot sec^{-1}$ were generally observed at least twice daily. Currents at the southern meter location were slightly slower, averaging 7 $cm \cdot sec^{-1}$ with a maximum recorded velocity of 23 $cm \cdot sec^{-1}$.

Sediment chemistry

Sediments at the Squaxin Island farm were much finer-grained than at the Clam Bay facility, and thus had considerably greater levels of organic carbon and total nitrogen. Sediment carbon concentrations were typically 2 to 3% at the Squaxin site in comparison to 0.3% in undisturbed areas of Clam Bay. The Squaxin site also differed from Clam Bay in that there were no gradients in sediment carbon or nitrogen concentration that could be attributed to farm activities (Figures 12 and 13). The degree of sediment enrichment was more or less uniform throughout the study area, and the slight variations were unrelated to farm proximity. There was no evidence of sediment enrichment above background levels even directly under the net-cages. One sample collected at the southern pen perimeter showed an organic carbon concentration approximately triple typical values, but this high concentration was not reflected in the two other samples at the same station.

Sediments at a depth of 4 cm (and probably much shallower) were highly reducing due to the fine grain size and reduced porosity of the Squaxin Island sediments (Figure 14). Reduction-oxidation potentials at the sediment-water interface ranged from 50 to 425 mv. This extreme variability is probably a consequence in the sharp gradient of redox potentials

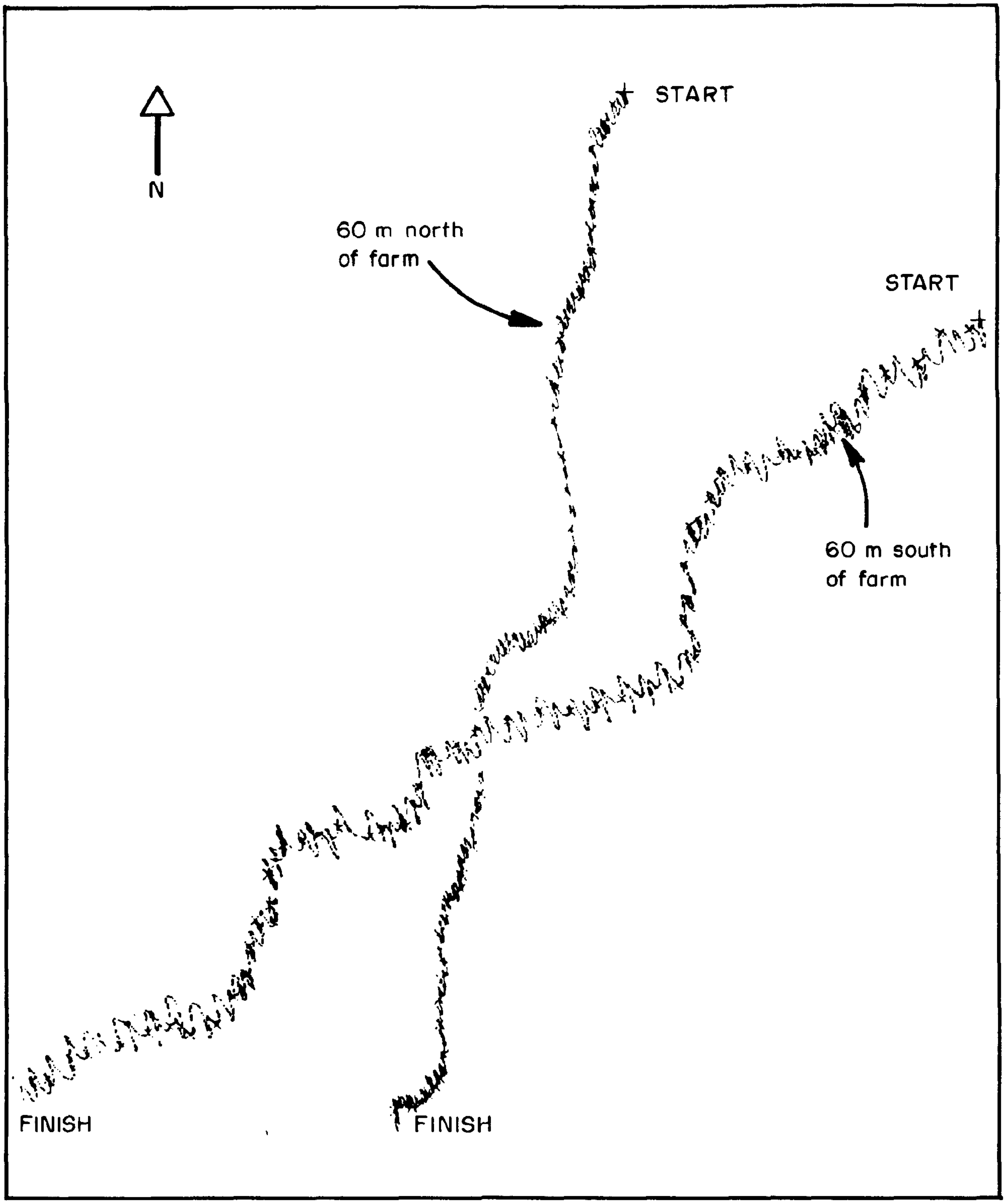


Figure 11. Progressive vector diagrams based on the two current meter records from the Squaxin Island site. X symbols indicate 24-hour intervals.

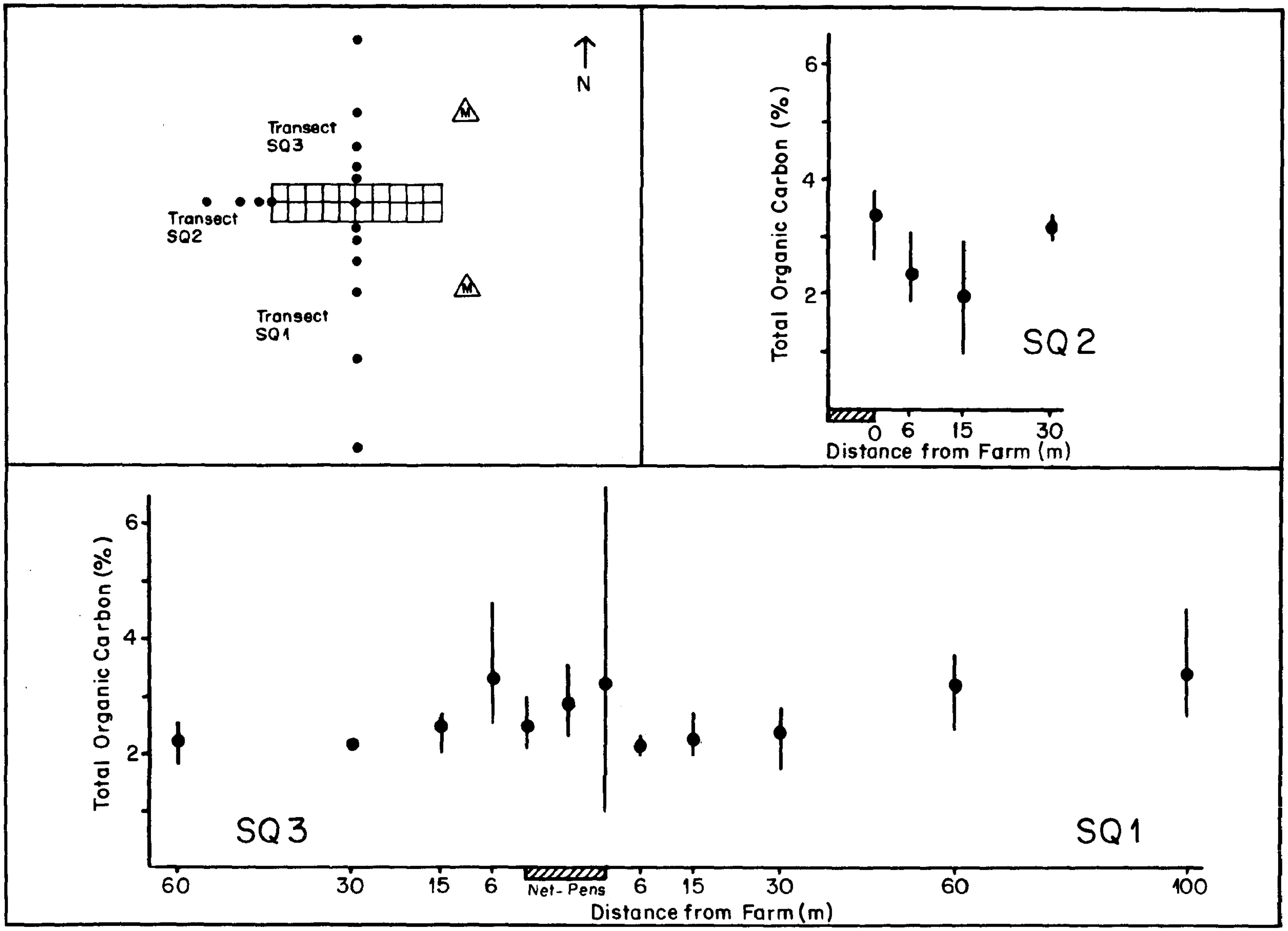


Figure 12. Total organic carbon concentrations in sediments surrounding the Squaxin Island farm. Range bars not shown if the range is less than the size of the mean symbol.

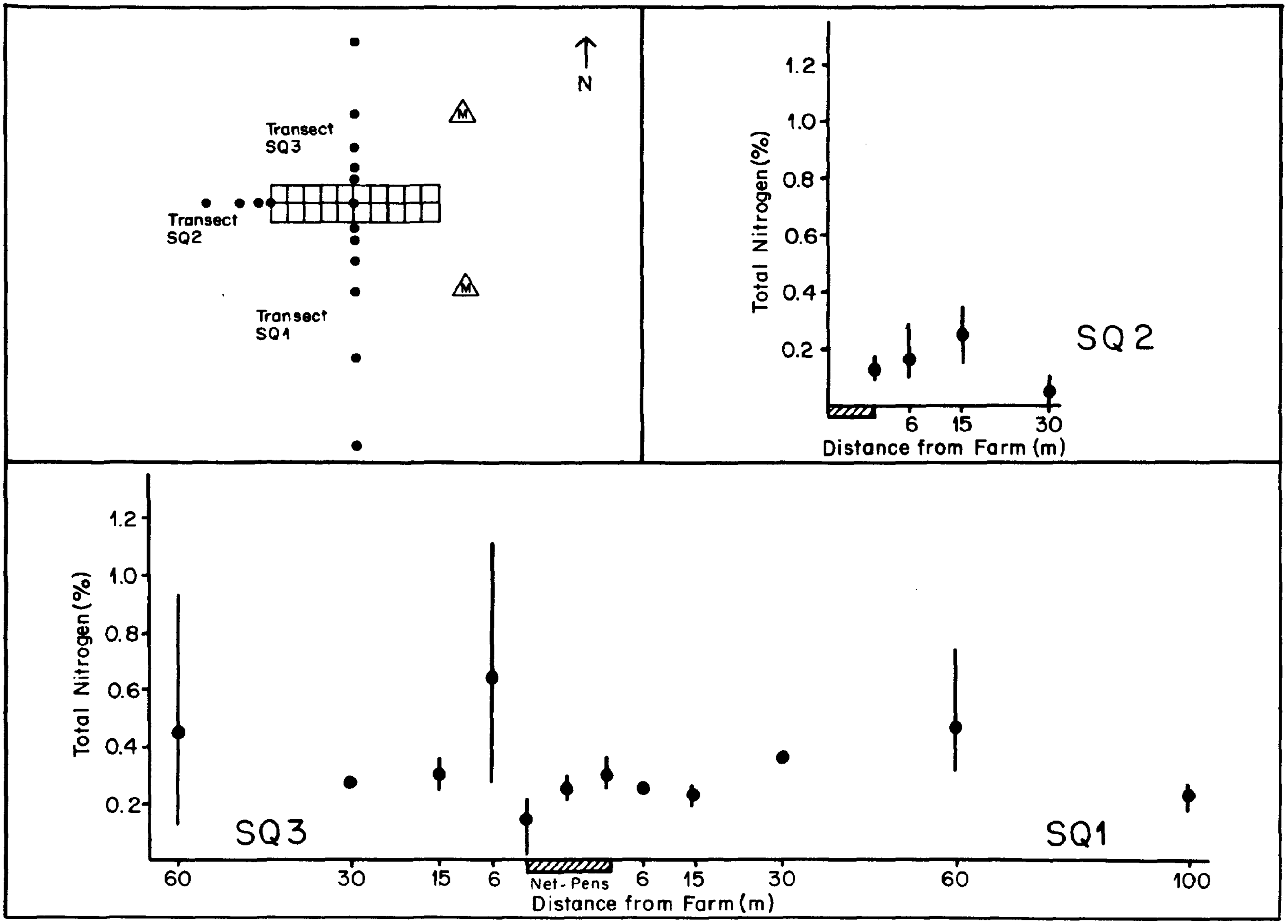


Figure 13. Total nitrogen concentrations in sediments surrounding the Squaxin Island farm. Range bars not shown if the range is less than the size of the mean symbol.

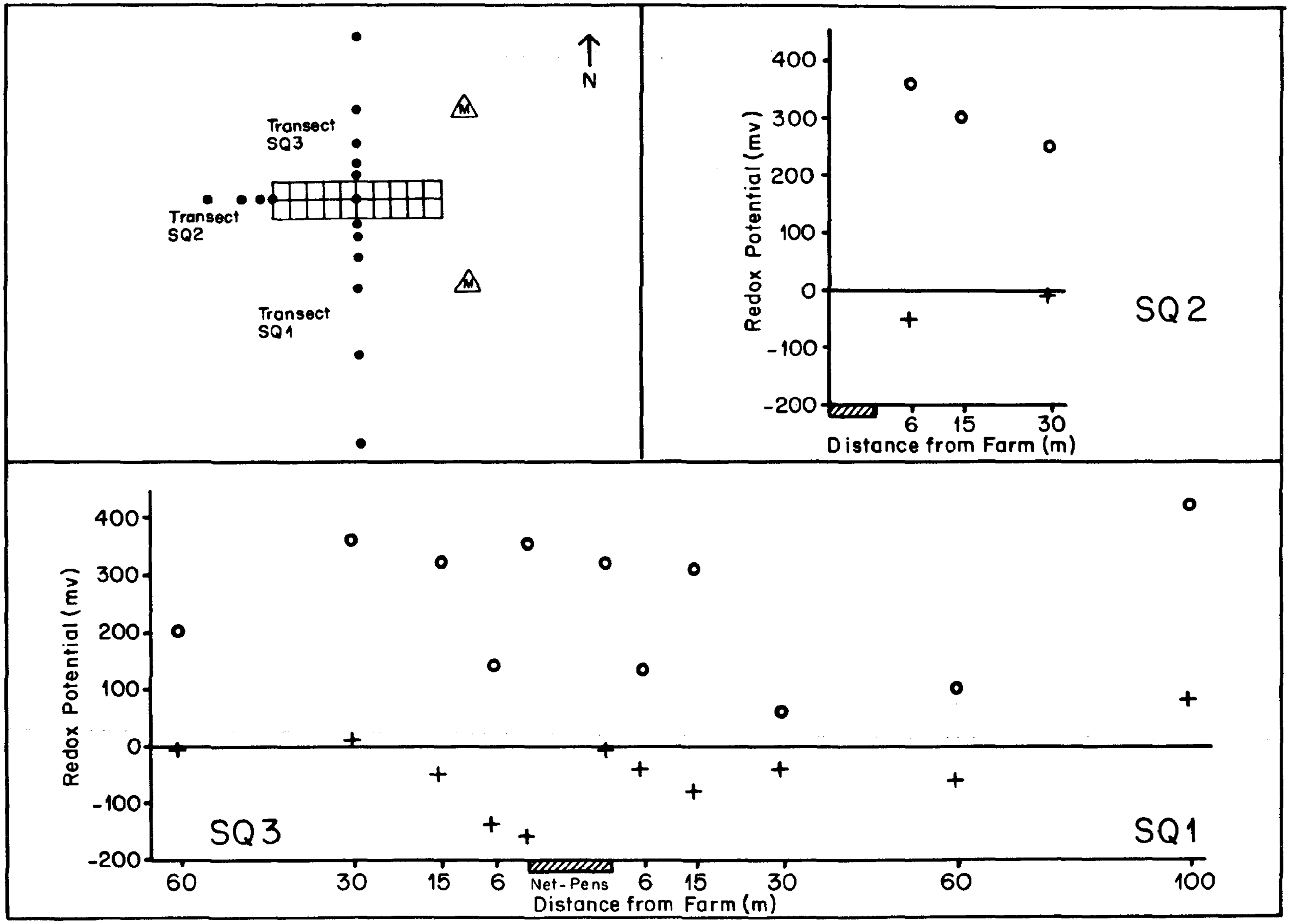


Figure 14. Reduction-oxidation potentials in sediments surrounding the Squaxin Island farm. Open circles represent potentials at the sediment-water interface; cross symbols represent potentials at a depth of 4 cm in the sediment.

in the upper few millimeters of the sediment column, and thus the measured potential can vary widely depending upon whether the probe is held a millimeter or two above or below the ill-defined "interface". Variability of the redox potential at a depth of 4 cm is probably due to the difficulty of collecting an undisturbed core with the high concentration of shell fragments, compounded by the difficulty of inserting the probe into the core without encountering an obstruction and further disturbing the core.

Redox potentials showed no pattern among the sampling stations that could be attributed to the presence of the farm. Unlike in Clam Bay, redox potentials were not consistently lower near the net-cages, except perhaps along transect SQ3.

Dissolved oxygen

Dissolved oxygen concentrations at 5 to 10 cm above the substrate were typically about 10 $mg \cdot l^{-1}$, and showed no depression near the farm site (Figure 15). Two samples had an unexpectedly high dissolved oxygen concentration indicative of either analytical error or an abrupt gradient in dissolved oxygen with distance above the seabed. The same qualifications expressed at Clam Bay regarding non-synoptic sampling apply here as well, but it does appear that farm activities are not depleting oxygen in the near-bottom waters.

Sediment traps

Seven sediment trap arrays were placed at the stations along transect SQ1, but only four could be recovered after the 15-day deployment (Table 5). Results from the array directly under the pens are problematic in that these traps captured only half the material of the other traps, and the material retained was comparatively low in organic carbon content. Since the mouths of the traps were only 1.5 m below the bottom of the net-pens at MLLW it was expected that a large amount of

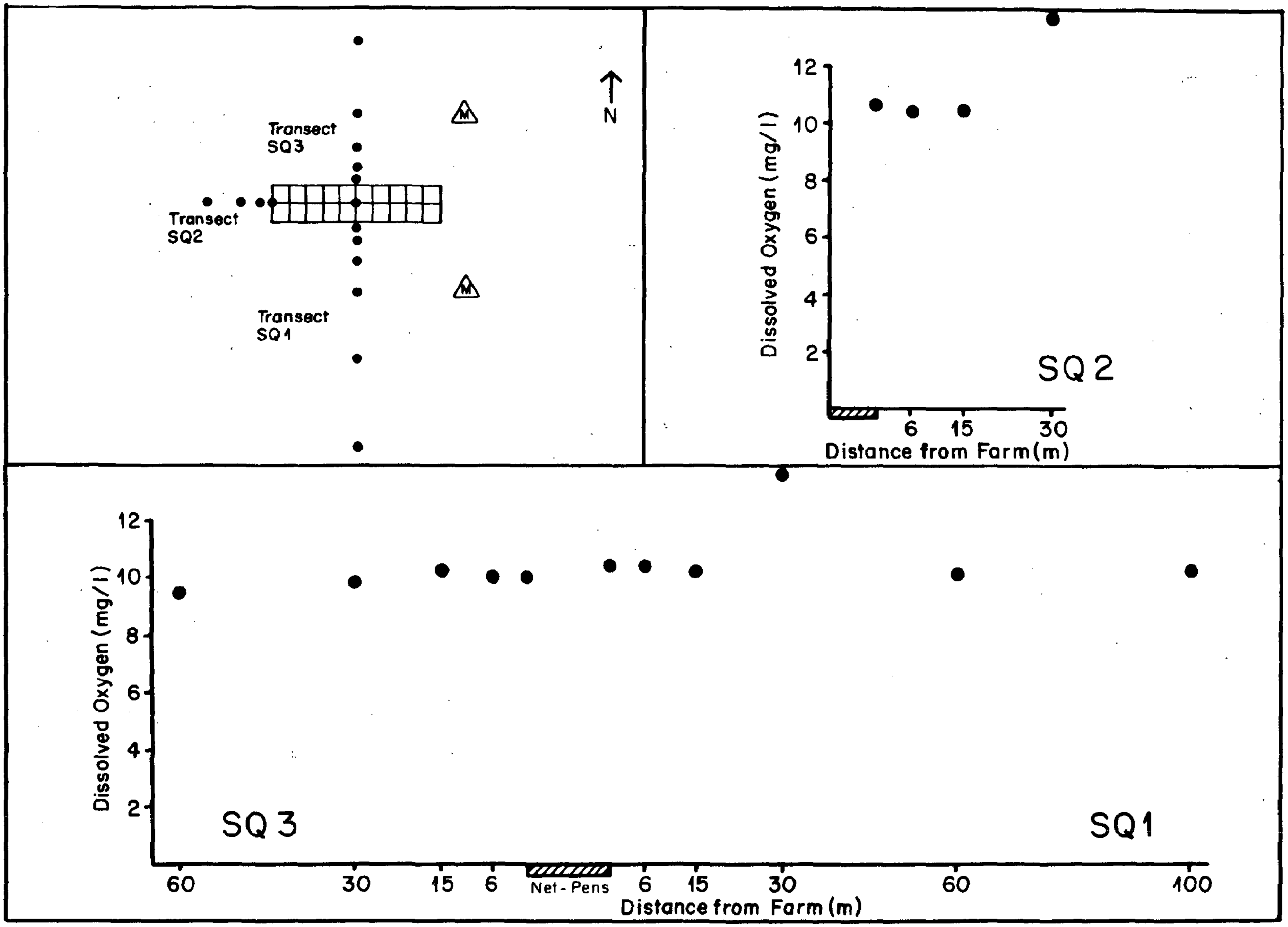


Figure 15. Dissolved oxygen concentrations in near-bottom water surrounding the Squaxin Island farm site.

Table 5
Sediment trap contents at the Squaxin Island farm
(Six measurements at most stations)

Distance from pens (m)	Sedimentation rate ($kg \cdot m^{-2} \cdot yr^{-1}$)	Nitrogen content (%)	Carbon content (%)	Carbon flux ($kg \cdot m^{-2} \cdot yr^{-1}$)
under pens	62.8	0.75	6.12	3.8
	65.2	1.29	7.85	5.1
	59.4	0.56	5.02	3.0
	58.0	0.63	5.19	3.0
	38.9	0.85	7.43	2.9
	41.1	0.99	7.62	3.1
MEANS	54.2	0.84	6.54	3.5
0	115.7	0.49	4.58	5.3
	88.0	0.43	3.95	3.5
	113.4	0.99	8.72	9.9
	119.7	0.66	6.23	7.5
MEANS	109.2	0.64	5.87	6.6
15	109.1	0.42	4.71	5.1
	118.4	0.39	4.21	5.0
	116.9	0.51	4.40	5.1
	111.3	0.64	4.15	4.6
	99.4	0.85	6.79	6.7
	106.0	0.60	5.20	5.5
MEANS	110.2	0.57	4.91	5.3
30	112.4	0.47	3.95	4.4
	98.9	0.35	2.13	2.1
	106.9	0.40	3.70	4.0
	108.7	0.48	5.22	5.7
	109.2	0.34	2.57	2.8
	107.7	0.27	1.64	1.8
MEANS	107.3	0.39	3.20	3.5

organic-rich material would have been collected. It is possible that this array may have become entangled in its own rope or in the nets during a very low tide, and turned on to its side at some time prior to recovery. This was the only array retrieved by a rope rather than by diver, and thus it is not known if it was properly positioned at the time of recovery.

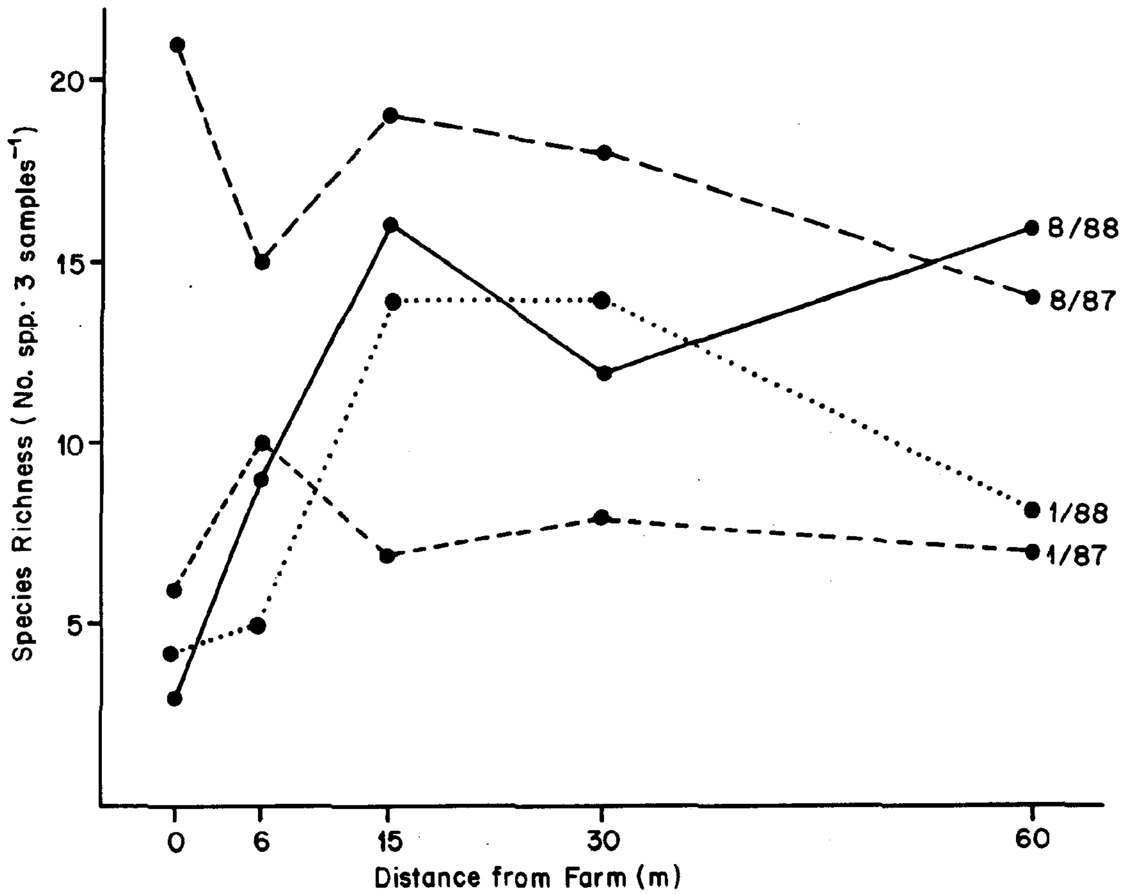
On the basis of data from the other sediment traps, the sedimentation rate was about 110 $kg \cdot m^{-2} \cdot yr^{-1}$ in the area from the farm perimeter to a distance of 30 m. Lacking data from greater than 30 m from the farm, it is difficult to establish whether the measured sedimentation rate reflects natural conditions or an enhanced sedimentation due to the presence of the farm. The organic carbon and nitrogen content of the trapped material was significantly different among traps (Kruskal-Wallis one way analysis of variance, $\alpha < 0.05$), and, in fact, the traps nearest the pens contained solids with a higher concentrations of both organic carbon and total nitrogen.

In comparison to the Clam Bay site, sedimentation rates at the Squaxin Island farm were two to three times greater (30 to 52 $kg \cdot m^{-2} \cdot yr^{-1}$ vs. 107 to 110 $kg \cdot m^{-2} \cdot yr^{-1}$). The collected material at Squaxin Island, however, contained only half the carbon and nitrogen concentration of the Clam Bay material. The fact that Clam Bay traps contained material with a relatively high organic content (30 to 100 times greater than background levels in surficial sediments) suggests that the collected material was largely farm-derived. At the Squaxin site the measured sedimentation rate was relatively high, yet since the organic content of the trapped material was only slightly greater than background concentrations in surficial sediments (1.5 to 2-fold), it is likely that the bulk of the collected material originated from natural sources.

Macrofauna

Macrofauna samples have been collected at most stations along transect SQ1 as part of routine monitoring by the farm operator. Baseline samples were collected in January 1987 after installation of the pens but prior to stocking with fish. Additional samples were collected in August 1987, January 1988, and August 1988. Intercomparisons among sampling events is complicated by variations in sample design between sampling periods and between replicates. In January 1987 each station was sampled with 3 cores of 5 cm diameter, each of which was sieved through a 0.5-mm screen. In all other sampling periods 10 cm diameter cores were used, two of which were sieved on a 1.0-mm screen and one of which was sieved on stacked 0.5 and 1.0-mm screens. Therefore, when comparing among sampling periods it should be recognized that the January 1987 sampling would tend to under-estimate species richness and abundance because of the smaller area sampled, but over-estimate these parameters because of the finer mesh size. All data are expressed on a "per three sample basis" which, in all but the January 1987 sampling, should be interpreted to include the material retained on a 1.0-mm screen in two samples per station and on a 0.5-mm screen in one sample.

The baseline samples (1/87) and those collected after 6 months of operation (8/87) demonstrated that the five monitoring stations were comparable in species richness and faunal composition and thus suitable for inter-station comparisons (Figure 16). In January 1988 after 12 months of operation there was a dramatic decrease in the species richness and abundance at the station under the perimeter of the pens and, to a lesser extent, at the station 6 m from the pens. This same decrease near the pens relative to the other stations along the transect was evident again after 18 months of operation (8/88). At this time macrofauna present under the pen perimeter included only the polychaetes Capitella cf. capitata (4 individuals), Nephtys cornuta fransiscana



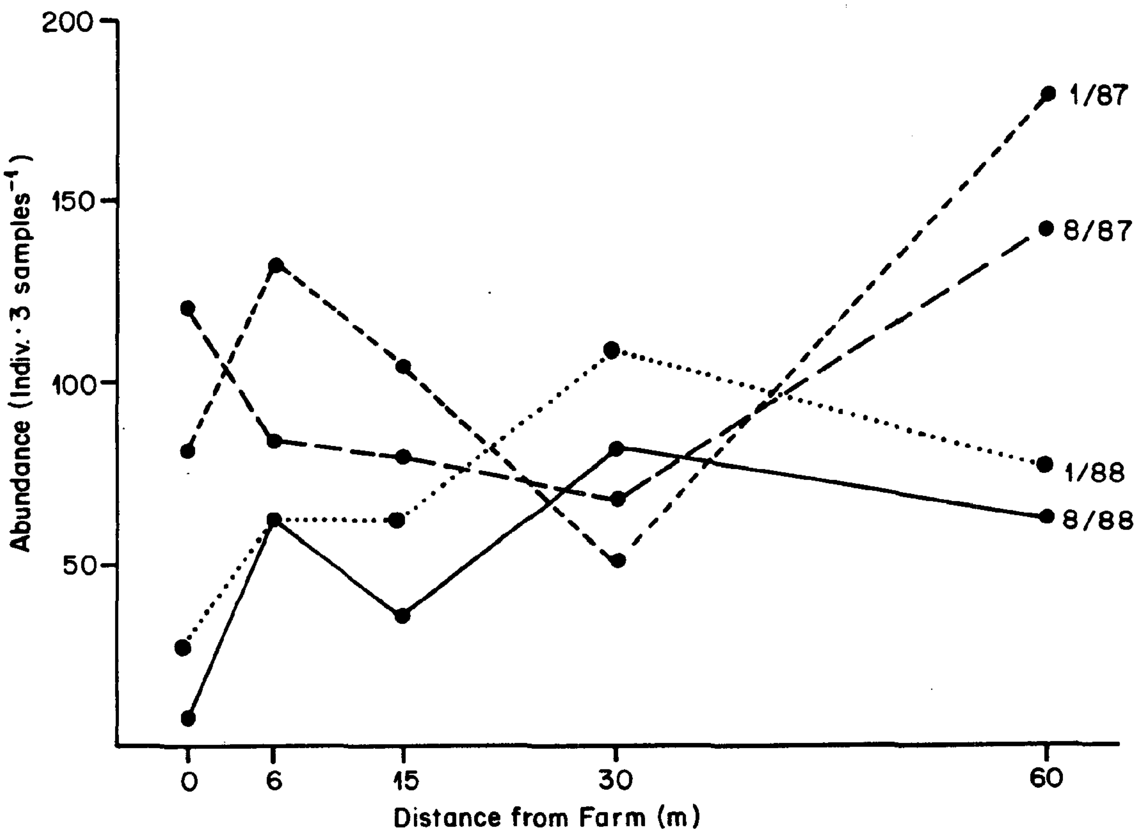


Figure 16. Trends in species richness and macrofaunal abundance along transect SQ1 at the Squaxin Island farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

(3 indiv.) and _Glycinde picta_ (1 indiv.). The depauperate fauna 0-6 m from the pens, an area which was formerly comparable to the other sites, indicates a localized impact of farm operation.

The distribution of _Capitella_ cf. _capitata_ (Figure 17) also suggests enrichment 0-6 m from the pen perimeter. No _C. capitata_ were found throughout the sampling transect during the baseline sampling (1/87). In all subsequent sampling periods, however, the species has been found in high densities at the 6 m site and at much lower densities at the pen perimeter and 15 m. Maximum density (945 individuals per three replicates, or 1875 $indiv \cdot m^{-2}$) was obtained in the most recent sampling (8/88).

Dispersion model

The dispersion model was run using the data of Table 6. The standing stock value used was based on the biomass present at the time of sampling. This value may seasonally vary by up to 50% depending on stocking and marketing cycles. No data were available on the actual amount of feed provided, so it was assumed that the fish were fed at a rate of 2% of their body weight per day, a rate typical of salmonid net-pen culture and the target rate of the Squaxin pen operators. All other model parameters were determined as described for the Clam Bay farm.

As a result of the shallow water depths, the sedimentation model predicted that the vast majority of feed and fecal waste would reach the bottom directly under the pens or within 5 m of the farm perimeter (Figure 18). A maximum loading rate of 14 kg $C \cdot m^{-2} \cdot yr^{-1}$ was predicted for most of the area under the farm. Lesser rates of deposition were predicted to the north and south, with essentially no accumulation of wastes to the east and west. Loading rates of 1 kg $C \cdot m^{-2} \cdot yr^{-1}$ or greater were limited to the area 15 m north and 28 m south of the farm site.

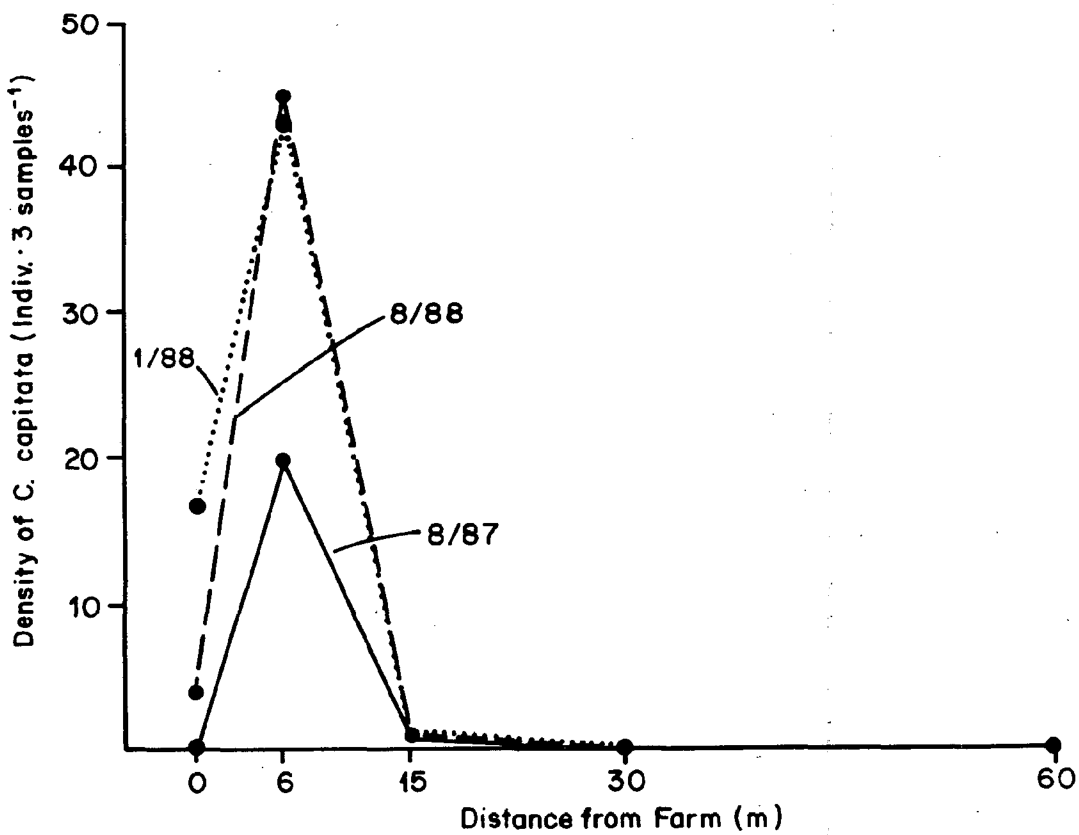


Figure 17. Density of the opportunistic polychaete Capitella cf. capitata along transect SQ1 at the Squaxin Island farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

Table 6
Data used in dispersion model at the Squaxin Island farm site

Farm size: 74 m x 16 m with long axis oriented east-west
Depth of pens: 3 m
Standing stock: 20 metric tons
Feeding rate: 400 $kg \cdot day^{-1}$
Organic carbon content of feed: 50%
Feed wastage: 15%
Settling velocity of feed: 14 $cm \cdot sec^{-1}$
Settling velocity of feces: 4 $cm \cdot sec^{-1}$
Water depth (approx. average of MLLW and MHHW along sampling transects): 7 m
Current data: June 6 - August 5, 1988; meter located 60 m north of farm site.

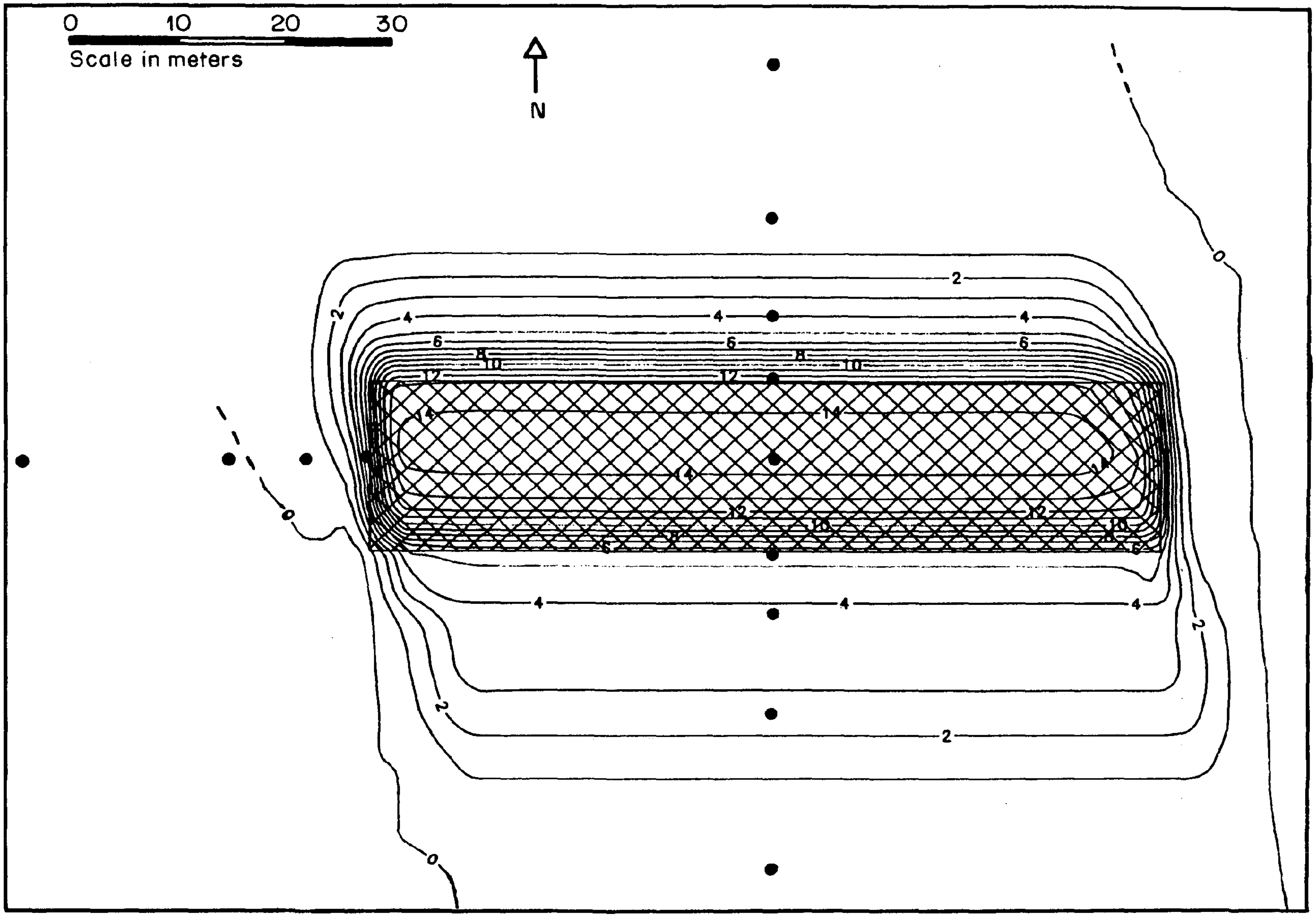


Figure 18. Model predictions of organic carbon loading to the seafloor at the Squaxin Island farm site. Contour units are kg $C \cdot m^{-2} \cdot yr^{-1}$. Dots indicate locations of sampling stations used for model verification. Stations 60 and 100 m from farm are not shown.

The predicted carbon fluxes at 0, 15 and 30 m south of the farm were 5.7, 2.5 and <1 kg $C \cdot m^{-2} \cdot yr^{-1}$, respectively. Over the same distance actual rates of carbon flux as measured by the sediment traps were 6.6, 5.3 and 3.5 kg $C \cdot m^{-2} \cdot yr^{-1}$. It should be recognized, however, that the model predicts deposition of solid wastes originating from farm activities, whereas the sediment traps do not differentiate between farm-derived particulates and deposition unrelated to the culture operation. It was noted above that the bulk of the material collected in the traps at the Squaxin Island site probably originated from natural sources such as resuspension of bottom sediments or terrigenous run-off. A true test of the model would require that the contribution of the natural sources be subtracted from the total material retained in the traps. The strength of the natural "noise", however, is so great compared to the pen "signal", that many more traps would have to be deployed to discriminate between these two sediment sources. The traps located farthest from the farm (60 and 100 m), which presumably would best represent the natural carbon flux, were not recoverable, so the magnitude of carbon flux typical for the area may be substantially less than the 3.5 kg $C \cdot m^{-2} \cdot yr^{-1}$ measured at at the 30 m trap. Model predictions vary from actual measurements by a factor of about 2 or less, depending on the particular trap and the assumed magnitude of the natural carbon flux.

The model was further evaluated by comparing predictions of deposition with sediment organic carbon concentration and redox potential (Figure 19). It should again be recognized that this comparison requires that the untested assumption be made that post-depositional processes are similar at all sampling sites. There was no significant relationship between model predictions and sediment carbon content, although predicted carbon flux was correlated with sediment redox potential (Spearman rank correlation, $\alpha > 0.05$). This correlation was largely attributable to the influence of the 0 and 6 m stations along transect SQ-3, an area which the model

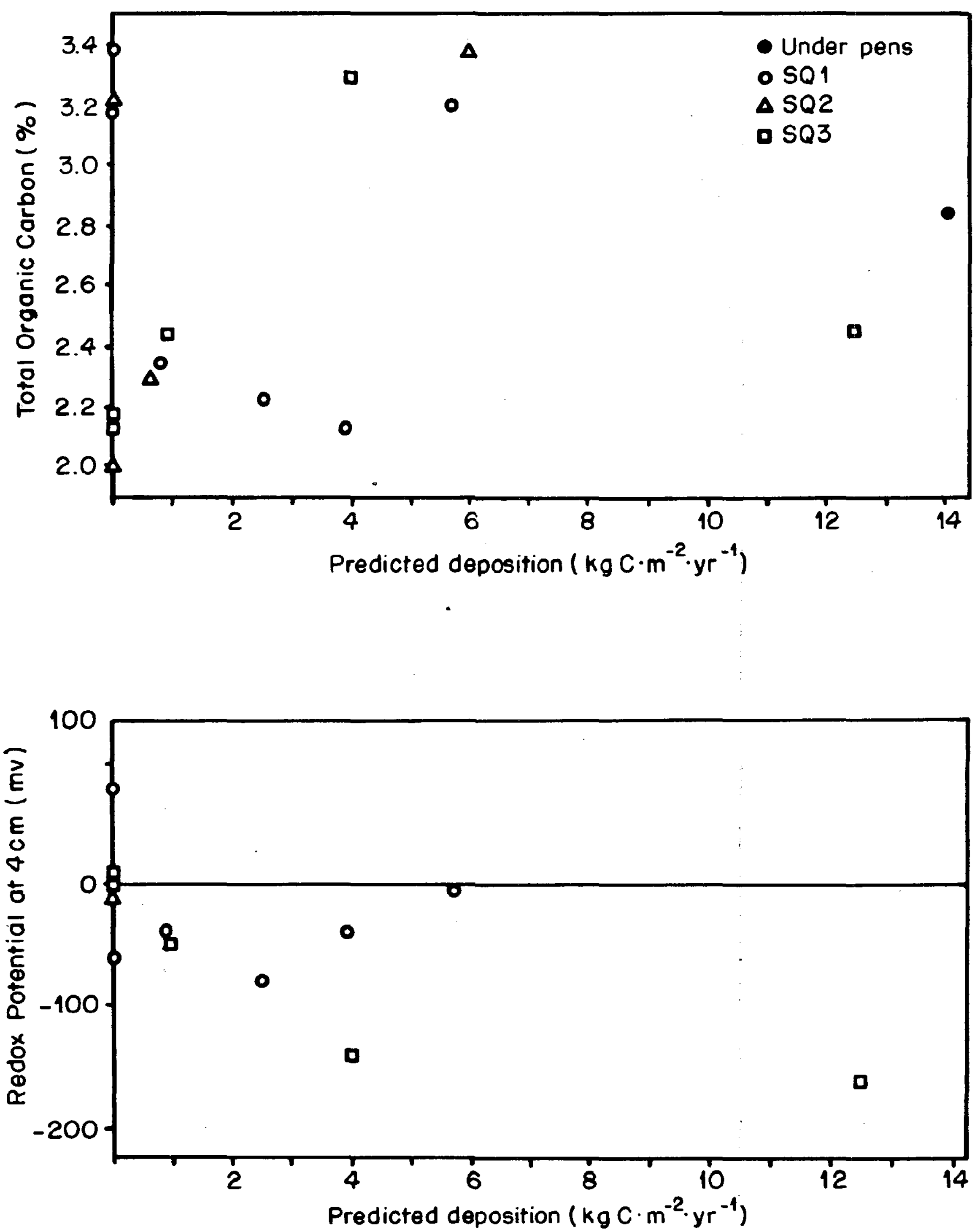


Figure 19. Comparisons of predicted carbon deposition based on the sedimentation model with field measurements of total organic carbon and redox potentials at the Squaxin Island farm site.

predicted to be among the most enriched and which also was found to have the lowest redox potentials.

DISCUSSION

CLAM BAY SITE

The various chemical parameters used to measure the effects of the farm operation on the sediments of Clam Bay showed good agreement, and provided a clear picture of the areal extent of impact. The culture of fish at the Clam Bay site has resulted in a measurable enrichment of the sediments directly under the pens and to a distance of approximately 30 m from the perimeter of the pens. The exact distance of impact depended upon the direction and the chemical parameter used as indicator of impact, but in all cases varied from 15 to 60 m. Within this area deposition of feed and feces has resulted in increased concentrations of total organic carbon and total nitrogen. Degradation of these organic wastes has depleted pore water oxygen, resulting in more negative reduction-oxidation potentials. At a few sites reducing conditions were found throughout the entire sediment column, although at most stations oxidizing conditions persisted to a depth of at least 4 cm. The enriched sediments did not measurably decrease oxygen concentrations in the overlying water at a height of 5 to 10 cm above the seafloor, although this does not exclude the possibility that reduced dissolved oxygen levels may be observed if measurements had been made on a scale of millimeters rather than centimeters.

The biological data (available only to the northwest of the farm) showed a severely disturbed community at the pen perimeter. This assemblage was comprised almost entirely of nematodes and Capitella cf. capitata. If the assumption could be made that a similar fauna existed wherever organic carbon concentrations were comparable (and given similar substrate type), then such a community might also be found 15 to 30 m south of the pens and at least 60 m to the east. Beyond this zone of severe disturbance, moderate effects of the farm were evident in communities 45 to 150 m from the site. This area was characterized by reduced species richness, biomass, and C. capitata densities in excess of 5000 indiv.$\cdot m^{-2}$.

All previous studies of the benthic effects of net-pen farming have reported localized impacts comparable to those found at Clam Bay. Brown et al. (1987) found normal conditions appearing at some point between 15 and 120 m from a farm in Scotland. In a survey of numerous Scottish farms, effects such as depressed reduction-oxidation potentials and appearance of Beggiatoa were commonly found up to 30 m from the farm site (Earll et al., 1984). Doyle et al. (1984) found effects extending 25 to 45 from a site in Ireland. The extent of effects at the Clam Bay site is comparable to these earlier studies based solely on sediment chemistry as a measure of effect. The biological indicators of disturbance, however, suggest effects extended to at least 150 m from the farm, approximately five times the distance typically reported.

SQUAXIN SITE

The effects of the Squaxin Island site on the benthos were more subtle and evident almost entirely on the basis of the biological data alone. There was little or no evidence of farm effects in the sediment organic carbon, nitrogen, redox, and dissolved oxygen data. One of the three samples collected below the southern pen perimeter showed a three-fold enrichment in organic carbon, but since such enrichment was not evident in the other samples at this site, the effects were presumably very patchy. The best physical/chemical evidence of farm impacts was provided by the elevated concentrations of organic carbon and nitrogen in material collected by the sediment traps nearest the pens. The macrofaunal data indicated reduced species richness and/or abundance from the pen perimeter to a distance of 6 m, and a peak in C. capitata abundance at a distance of 6 m. C. capitata, an indicator of enriched sediments, first appeared in the area 6 months after culture began, and was increasingly abundant 12 and 18 months after the initiation of culture. For comparison, Brown et al. (1987) reported changes in sediment chemistry and appearance of C. capitata 3 months after initiation of culture in a Scottish loch. Mattson and Linden (1983) monitored benthic conditons after installation of mussel longlines and found a period of 6 to 15 months were required for replacement of the original fauna with an assemblage characteristic of enriched conditions.

The limited measurable physical/chemical effects of culture and the highly localized biological effects at the Squaxin site are suprising given that the bottom of the pens are only 2 m above the seafloor at low tide. There are two possible explanations for this observation. First, the current velocities at the Squaxin site are suprisingly high, and only slightly less than near-bottom currents at Clam Bay. The 15 to 18 $cm \cdot sec^{-1}$ measured twice daily at the Squaxin site may promote dispersal of the solid wastes, particularly if the narrow distance between the nets and the seafloor promotes a channeling effect and an acceleration of currents directly under the pens. Secondly, the Squaxin pens have only been in place for 18 months in comparison to approximately 13 years for the Clam Bay farm. Benthic conditions at the Squaxin site may continue to deteriorate with time, but a recent change in farm operation may slow or halt this deterioration. The operators of the Squaxin site have recently decided to curtail aquaculture operations and use the pens primarily for delayed release. The seasonal nature of use should minimize further effects on the benthos.

ASSESSMENT TECHNIQUES

It should be noted that at both Clam Bay and the Squaxin sites, the macroinfaunal data showed evidence of alteration in areas where sediment chemistry data failed to show farm effects. Biological data appeared to be a more sensitive indicator of disturbance, and therefore suggest that chemical information alone can not adequately define the extent of benthic impacts from net-pen culture. The biota are certainly better integrators of temporal variation, and they also undoubtedly are responding to chemical and physical parameters unmeasured in conventional surveys.

The reduction-oxidation measurements proved valuable, particularly at the Clam Bay site where redox potentials closely mirrored gradients in organic carbon and nitrogen. Redox measurements have several advantages over carbon and nitrogen analysis, most notably the fact that results are obtained in the field immediately after sampling and there are no analytical costs once the pH meter and redox electrode are acquired. Redox measurements worked well in the sandy sediments of Clam Bay where vertical gradients in sediment redox potentials were gradual, but were more problematic in the muddy sediments of the Squaxin sediments. In these fine-grained sediments much of the vertical change in redox potentials occurs in a thin veneer of sediments at the sediment-water interface. Measured potentials (and the identification of culture effects) become highly susceptible to minute variations in the extent to which the probe is inserted. Conventional redox probes are approximately 1 cm in diameter and do not permit the fine-scale resolution necessary in muddy sediments. Micro-electrodes are available, but are expensive and subject to frequent breakage.

MODEL EVALUATION

The dispersion model was tested on its ability to predict: 1) the absolute loading of particulate wastes; and 2) the relative loading among numerous sites. The former evaluation was done by comparing the quantity of material retained in the sediment traps with the quantity that the model predicted would accumulate at the trap location. At the Squaxin site natural deposition made discrimination of the pen contribution difficult, but the predicted loading appeared to differ from measured values by factors of 2 or less. In Clam Bay the predictions were in good agreement with the measured loadings, differing by factors of 1.2 and 1.4 in the two trap arrays.

It should be recognized that there are inherent difficulties of measuring actual carbon flux and there are many potential artifacts associated with the use of sediment traps (Butman, 1986). Nevertheless, if the sediment trap data can be taken as an accurate representation of actual carbon flux, then model errors of only 1 to 2-fold demonstrate remarkably good predictive capability of the model.

The second test of the model was to compare predicted loadings at all stations with measured values of sediment carbon content and redox potential. At both farm sites the model predictions of carbon flux showed a statistically significant correlation with redox potential. Sediment carbon content was correlated with model predictions only at the Clam Bay site. The better model performance at Clam Bay than at Squaxin Island was probably due to the greater amount of sediment resuspension at the latter site. The sediment trap data and the lack of pronounced physical/chemical gradients with distance from the farm both suggest a high degree of sediment transport and resuspension. Under such conditions it is not suprising that the sites predicted to have the greatest carbon input rate failed to show the highest levels of sediment enrichment. This illustrates the shortcomings of using static measurements (sediment carbon concentration) as a test of rate measurements (model predictions of carbon flux).

The model predictions were correlated with sediment redox potential at both of the sites examined, and with carbon concentration at one of the two sites. The performance of the model in Puget Sound is in general agreement with tests of the model in Scotland where, out of six farms, the model predictions correlated with measured redox potentials at all six farms and with carbon at two farms (Gowen et al., 1988).

Ideally, the model should be capable not only of predicting the extent of chemical change in sediments but also the degree of biological disturbance. Such predictions are much more difficult for the biological effects of a given rate of carbon flux is likely to be habitat specific. Communities of sandy substrates may not respond to a given flux in the same manner as mud bottom communities. The model has not been refined to the point where reliable biological predictions are possible, but some preliminary observations have been made. In model tests in Scotland, it was found that severely disturbed sites, defined as containing four or fewer macro-faunal species, had predicted loadings of at least 1.8 to 4 kg $C \cdot m^{-2} \cdot yr^{-1}$ (Gowen et al., 1988). At the Squaxin Island farm four or less species were found where the predicted loading was 5.7 kg $C \cdot m^{-2} \cdot yr^{-1}$ and undisturbed communities were present where predicted loadings were 2.5 kg $C \cdot m^{-2} \cdot yr^{-1}$ or less. At Clam Bay the fewest number of species (9) were found where the predicted deposition was 2.5 kg $C \cdot m^{-2} \cdot yr^{-1}$, although more moderate impacts were evident at lower rates of carbon flux. Other than order-of-magnitude approximations, the existing data base is inadequate to determine a threshold carbon flux beyond which biological effects are likely. Nevertheless, such estimates may be possible with additional refinement of the model and recognition of the habitat-dependence of biological impacts.

The model has performed well in both Puget Sound and Scotland, yet it has inherent limitations which should be recognized:

1) As discussed earlier, the model does not take into consideration any post-depositional processes that may occur, or differences in the rate of these processes among sites. For example, the model only predicts the point at which a settling particle impacts the bottom and not any reuspension or transport that may occur later. Model predictions would be invalidated if the degree of

resuspension varied throughout the study area as might be the case with differing substrate types or pen-related alteration of current flow.

2) The model, as currently formulated, is incapable of coping with variations in bottom topography. At the Clam Bay site a single water depth (18 m) had to be assumed despite the fact that water depths varied from 10 to 30 m over the predicted area of depositon. The net effect is that in shallow areas the model over-estimates the lateral extent of depositon, and under-estimates the lateral extent in deep areas. This shortcoming could be remedied but would dramatically increase the computational requirements of the model.

3) An arbitrary assumption had to be made that feed wastage at both farm sites was 15%. Puget Sound farm operators typically claim a wastage factor of about 5%. The magnitude of predicted organic carbon loading to the bottom is dependent upon the degree of wastage assumed as demonstrated by Figure 20. (Note also in this figure the depth-dependence of the loading with reference to the limitation under point #2 above.) A reduction in the wastage factor from the 15% employed in this analysis to the 5% claimed by Puget Sound operators would result in a decrease in predicted organic carbon loading of about 15%. In fact, there is probably no reliable estimate of wastage in Puget Sound or throughout the industry in general. Until there are reliable estimates of feed wastage, neither this nor any other model will be able to predict loading with a high degree of accuracy. The wastage-dependence of loading shown in Figure 20 also illustrates the effect that the operator's feeding practices can have on waste production, and the environmental benefits to be gained by reducing wastage.

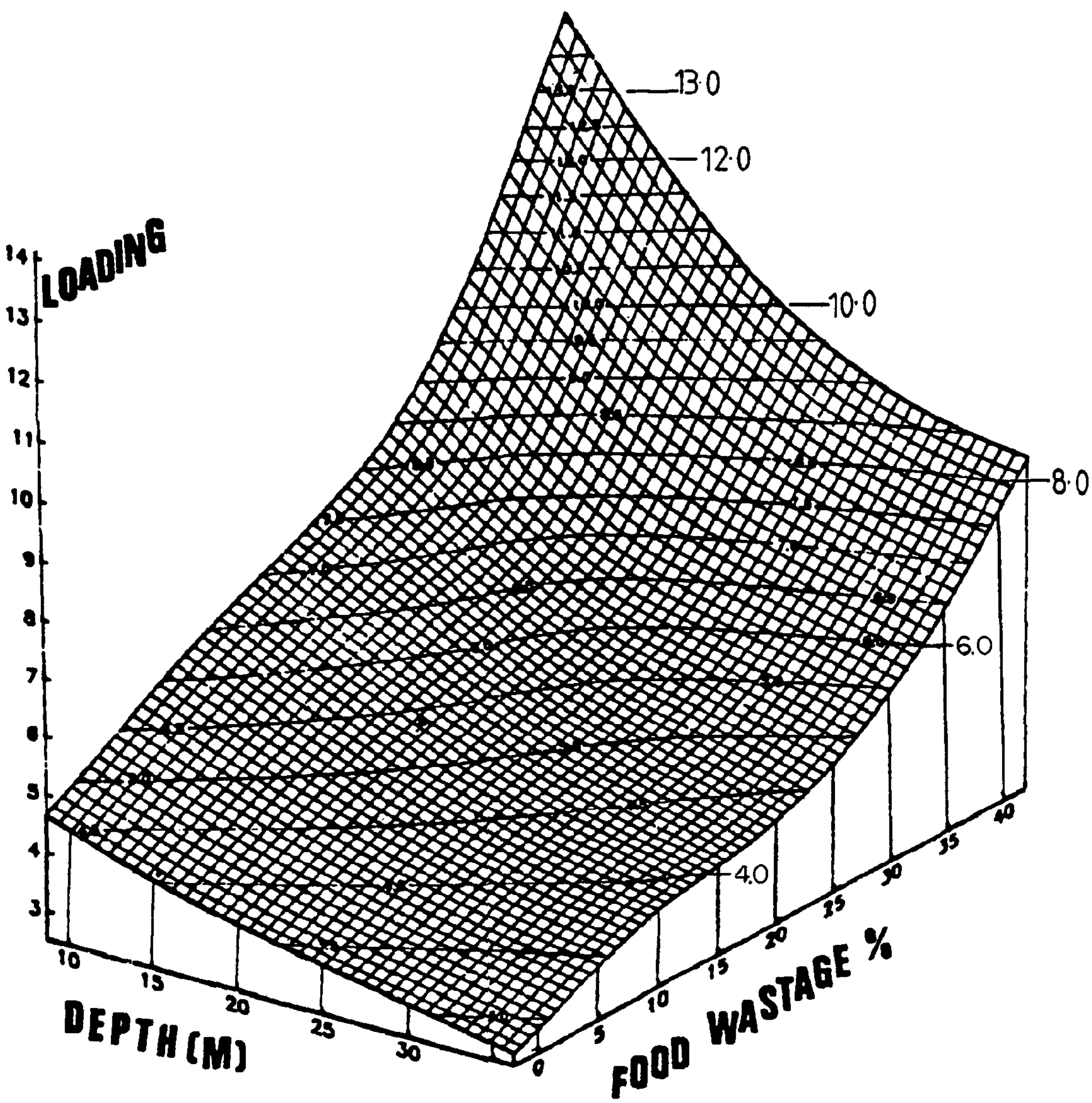


Figure 20. The relationship between food wastage, depth and organic loading to the sediment for a hypothetical set of current data. Loading rates are given as g C·m^{-2}·day^{-1}. (From Gowen et al., 1988).

4) The model requires the designation of a single settling velocity for feed and a second settling velocity for feces. As noted by Thomson (1986), however, the size and density of particulates released from a net-pen are likely to depend upon the species and size of the fish, the type and pellet size of the feed, and the amount of physical disturbance induced by either water current or fish activity. In additon to these potential variables, particulate wastes are not uniform in size or density, and thus can not be adequately characterized by a single settling velocity, or even the two velocities of the model. Settling velocities of culture wastes are best described by a frequency distribution, and the model therefore requires that a major oversimplifying assumption be made.

5) It is not possible to describe variations in the flow field attributable to the presence of the pen structures, and how these variations may influence depositon. If the model is used for siting in a pre-development stage, the installation of the pen structures may modify the predicted magnitude and distribution of waste loadings. The effect of pen installation on waste dispersion is, however, likely to be small in most cases particularly when the pens occupy a small proportion of the total water column.

6) The hydrographic input to the model is based on current records at a single point, and there is no allowance for changes of the flow field along a particle's trajectory. The current velocity and direction measured at the meter mooring may not be representative of current regimes on other sides of the farm complex or over the entire area of deposition. At the Clam Bay farm the two current meters gave very different pictures of current patterns. The model was run using data from the eastern meter since

this site would be less subject to the complications of bay geomorphology, but the model results would have been somewhat different had data from the other meter been used. The effects of lateral variation of currents on model predictions are especially pronounced at Clam Bay because of the atypically large size of the farm and shoreline effects on current patterns. At the Squaxin Island site and at other farms of small to moderate size the effect of lateral variations in current patterns may be negligable and ignoring these variations in the model may be justified.

7) The model, as presently formulated, is incapable of dealing with depth-related variation in current flow. With increasing water depth, the probability increases that currents measured at a single depth are unrepresentative of the multiple current regimes a particle encounters during settling to the seafloor. In the present study the meters were positioned at a depth approximating half the distance between the bottom of the pens and the substrate. In some situations multiple current meters at several depths may be necessary to accurately predict waste dispersal.

8) The model has no mechanism by which to consider duration of culture. The magnitudes of organic carbon loading were comparable at the Squaxin and Clam Bay sites, yet the effects on sediment chemistry were much greater at Clam Bay. This difference, which may be due to the short period of time that the Squaxin site has been in use, can not be incorporated into the model.

Despite the limitations of the model, it represents the best means currently available to predict the magnitude and extent of culture impact on the seafloor. The model has performed well both in the present study and in previous tests in Scotland, yet because of its limitations and the necessary simplifying assumptions, the model should be used cautiously as a predictive tool. As indicated by the probable high degree of transport and/or resuspension at the Squaxin Island site, consideration must be given to site-specific conditions which violate model assumptions and therefore make predicted loadings subject to error. On a fine scale (predicting carbon flux at a specific point), model loading predictions appear to be reliable to within a factor of two in most cases. While this is generally adequate for site assessment, the potential error should be recognized and compensated for in identifying areas of potential impact.

On a broader scale (predicting the affected area), model predictions appear very reliable, for at five sites examined in Scotland, the model predicted that the 1 kg $C \cdot m^{-2} \cdot yr^{-1}$ isopleth would extend up to 15 to 30 m from the farm perimeter. In the present study, the model predicted this rate of loading up to 28 and 70 m from the Squaxin and Clam Bay sites, respectively. Areal extents of impact of this magnitude are consistent with observations from the present study and other studies reported in the literature.

The current information collected as input to the model is extremely useful both from the perspectives of environmental protection and farm husbandry. The current meters deployed in this study measured velocity and direction every 15 minutes for a period of 60 days. Such information is invaluable not only to predict the dispersal of solid wastes but to determine mooring requirements, rates of water renewal in the pens, and duration of slack water (which may be the limiting water quality parameter in maintaining suitable growing conditions).

The model is useful in condensing a massive data set of current measurements into a single summary figure interpretable by non-specialists. It should therefore be helpful in explaining probable impacts in public hearings and similar forums.

The model is also helpful in identifying sites which would be clearly unsuitable for culture. Given the current state of knowledge it is not possible to define the impacts of a given loading rate, however severe biological disturbance has been observed in Scotland where predicted loadings were as low as 1.8 kg $C \cdot m^{-2} \cdot yr^{-1}$. At some unquantified level below this loading, development of a site is unlikely to have significant effects on the benthos. At most farms examined in Washington and Scotland, loading rates directly under the pens range from 6 to 14 kg $C \cdot m^{-2} \cdot yr^{-1}$. Where loading rates are far in excess of these values, the generation of hydrogen sulfide by enriched sediments and the consequent effects on the cultured fish themselves would be of serious concern.

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APPENDIX B

MODELING OF PARTICULATE DEPOSITION UNDER SALMON FISH FARMS

MODELING OF PARTICULATE DEPOSITION UNDER SALMON NET-PENS

by:

William P. Fox, P.E.

Parametrix, Inc.
P.O. Box 460
Sumner, WA 98390

for:

Washington Department of Fisheries, AX-11
115 General Administration Bldg.
Olympia, WA 98504

Job No. 35-1747-02

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INTRODUCTION

One of the observed effects of some salmon net-pen facilities on the environment has been organic enrichment of the underlying soils from the deposition of fish feces and uneaten feed. Under separate report to the Department of Fisheries, Drs. Donald Weston and Richard Gowen have examined deposition rates, chemical changes and biological impacts under two net-pens sited in Puget Sound. Their evaluation included a predictive deposition model developed by Gowen.

A separate modeling approach has been used in the evaluation of several proposed net-pens recently by Parametrix, Inc. The purposes of this report are: (1) to run the Parametrix model for the same sites modeled by Gowen and comment on the comparative results, and (2) modify configuration, orientation and density of the pens and evaluate the sensitivity of predicted deposition rates to these variables.

MODEL DESCRIPTION

The Parametrix model is a modification of a model developed by EPA (1982) to predict the deposition of particulates from sewage treatment plant outfalls in coastal waters. This model has already been applied to several proposed net-pens in the State of Washington. The model relies on average speed and frequency along the principal and minor axes to predict excursion distances from the pens and areal deposition rates for settleable materials of distinct settling velocity. A sloping bottom can be accounted for in the model. Comparison of the Parametrix model with Gowen's model will be saved for the Discussion.

The Parametrix model includes evaluation of post-depositional processes related to decay of the organic material. The organic material will decay as it accumulates on the sea floor. When the rate of deposition matches the rate of biodegradation, a steady-state accumulation of organic material will result. Decay of organic material will create an oxygen demand in the bottom waters in the vicinity of the net-pens. The EPA methods are used to predict the resulting steady D.O. depletion in the near-bottom waters.

RESULTS: CLAM BAY SITE

Currents. Like Gowen's model, the Parametrix model is based on the current meter located 100 m east of the farm site (#F2053). The current rose from this meter is shown in Figure 1. Each of the current measurements has been catalogued into one of eight 45° directional "bins." The percentage of currents falling within each bin and the average speed of those currents are indicated by the rose. The length of each rose petal is proportional to the percentage of currents in that direction. The current rose for the Clam Bay site used in the model indicates the predominant current direction falls within the bin from 90° to 135° (ESE). The average currents along the major and minor axes of the net-pens used in the model are adjusted for the frequency and strength of currents in each direction (for example, the fastest currents occur from 315° to 360° but are not very frequent, thus are not weighted as high as the easterly currents).

Wasteload and Settling Velocities. The method of determining wasteload and settling velocities used by Gowen is different than that used for this model. The wasteload assumed for this model study is consistent with the wasteloads assumed in earlier modeling efforts by Parametrix for net-pens in Puget Sound (Harding Creek, Discovery Bay, and North Skagit Bay). The Gowen model is based on a carbon mass balance, whereas the Parametrix model accounts for total solids. The results modeled herein are converted to carbon for comparison with Gowen's results in the summary results, based on 48 percent carbon content for feed, and 80 percent for feces.

The wasteload and settling velocities assumed for the Parametrix model are based on an annual production of 617 metric tons, Gowen's published data for European farms, and other European researchers (Gowen 1987). Lost feed would be about 10 percent of the total feed. The data used in this modeling are tabulated below:

Waste Component	Total Solids Loading	Total Carbon Loading	Percent	Settling Velocity
Uneaten Feed	430 kg/d	206 kg/d	40%	10 cm/s
Large Feces	325	260	30	5
Small Feces	325	260	30	2
Total	1,080 kg/d	726 kg/d	100%	

By comparison, Gowen's model assumed 317 kg C/day lost feed and 540 kg C/day feces, for a total loading of 857 kg C/day.

Model Runs. The model was run for the existing pen size and orientation and four other configurations as summarized below:

Run	Description
1	Existing pen size and orientation
2	Rotate existing pens 90°
3	3 round pens with same total surface area
4	Increase pen width by 50 %
7	Decrease fish production 50 %

The results of each model run are summarized below and in the Figures attached at the end of this report (except Run 7 which would have the same areal coverage as Run 1, with 50 percent of the deposition rate). The table below includes only the maximum predicted impact, which would be concentrated directly under the pens. Total accumulation is based on a steady-state decay of organic material. The model output is provided at the end of this report for all runs.

Run	Total Deposition kg/m^2/yr	Organic Deposition kg C/m^2/yr	Total Accumulation kg/m^2	D.O. Depletion mg/L
1	14.7	9.3	4.0	0.13
2	9.8	6.1	2.7	0.04
3	10.6	6.5	2.9	0.08
4	10.8	6.9	2.9	0.11
7	7.4	4.6	2.0	0.07

RESULTS: SQUAXIN SITE

Currents. The model runs for the Squaxin site are based on the meter #F2057 located 60 meters north of the existing pens. The current rose for this meter is shown in Figure 2. The rose reveals a predominant NNW by SSE current axis. The SSE component is slightly less frequent, but much stronger than its counterpart. Current speeds used in the model are handled similar to the Clam Bay site.

Wasteload and Settling Velocities. The Squaxin site is much smaller than the Clam Bay site. The assumed wasteloads and settling velocities are tabulated below:

Waste Component	Mass Loading	Mass Percent	Settling Velocity
Uneaten Feed	40 kg/day	40 %	10 cm/sec
Large Feces	30	30	5
Small Feces	30	30	2
Total	100 kg/day	100 %	

Model Runs. The model was run for the pen configurations as summarized below:

Run	Description
5	Existing pen size and orientation
6	Rotate existing pens 90°

The results of each model run are summarized below and in the figures and printouts attached at the end of this report.

Run	Total Deposition kg/m^2/yr	Total Accumulation kg/m^2	D.O. Depletion mg/L
5	11.9	3.3	0.02
6	17.2	2.7	0.05

DISCUSSION

Comparison with Gowen Model. The basic calculation in both models, horizontal displacement of settleable particles, is governed by the same function of settling velocity and current velocity. However, Gowen's model simulates individual particle trajectories for each current velocity from the current meter data, whereas the Parametrix deals only with averages. Accordingly, the Gowen model requires more input data and is capable of a producing a larger number of sediment contours and more precise deposition pattern.

Unlike the Parametrix model, Gowen's model does not consider sloping topography, multiple settling velocities or post-depositional biological processes. However, Gowen's model could certainly be modified to include these additional features. Although these features are desireable, the uncertainties regarding wasteload and post-depressional processes exceed the precision achieved by these features.

Neither model accounts for dissolution, suspension or resuspension of particles by high currents. However, a very detailed field investigation of the spatial distribution of currents near each site would be necessary to predict impacts at remote locations if material is resuspended. Resuspension and maintenance of fish feces in suspension under turbulent conditions would be a valuable future research topic.

Comparison of Model Results. Gowen's model produces a more detailed map showing deposition contours ranging from 0 to 12 kg C/m^2/yr for Clam Bay, with 1 kg C/m^2/yr intervals. The Parametrix model reveals only 3 contours, with an average of 9.3 kg C/m^2/yr centered under the pens (Run 1). Gowen's assumed wasteload was greater than that assumed for the Parametrix model. Given the uncertainties regarding wasteload assumptions (discussed below) and the greater resolution possible with Gowen's model, the results appear compatible.

As discussed in the model description, the Parametrix model accounts for the post-depositional process of decay. The assumptions made are generally conservative, but may be useful for management uses. The accumulation mass and thickness would be masked in areas where natural deposition is also occurring. In each case modeled, the predicted D.O. impact would be negligible, which is consistent with the observations of Weston. The D.O. function in the model would be useful to flag potential problems, but could not be relied on for an accurate prediction if oxygen problems are anticipated.

Sensitivity Analysis. The results of Runs 1 through 4 and 7 indicate the sensitivity of deposition to various factors. Runs 1 through 4 represent an equal number of fish, or wasteload. Run 7 reveals that the most effective way to reduce deposition is to reduce the wasteload.

For a given wasteload, the greatest mitigation is achieved by orienting the pens perpendicular to the predominant current direction (a reduction of 33 percent in this case: see Runs 1 and 2). In this respect, the Squaxin site is already mitigated, as evidenced by a like increase by rotating the pens by 90 degrees (see Runs 5 and 6). Of course, engineering and navigation considerations may not allow this mitigation measure.

Separation of the pens into several pods may also mitigate deposition. Essentially, the impact would be spread over a greater area. In this example, a reduction of 28 percent would be achieved by the configuration chosen for Run 3. The reduction at any proposed site would be site specific and a function of the size and separation of the individual pens.

Run 4 increased the dimension perpendicular to the predominant current by 50 percent. A reduction in deposition of approximately 25 percent is anticipated. Again, the reduction obtained at any site would be specific to that site. An increase in the dimension parallel to the predominant current would have little effect.

CONCLUSIONS

The primary conclusions of this analysis follow:

1. Gowen's model produces a deposition map of better resolution than the Parametrix model. The Parametrix model crudely accounts for uniformly sloping bottom topography and post-depositional decay, and can accept any number of settling speeds or vertical variation of current speed.

2. Improvements could and should be made to both models regarding suspension and resuspension of depositional materials.

3. Current speed and direction relative to the pens are critical to deposition. Fecal material from the pens may remain suspended at some threshold current speed. If current speeds are below this threshold level, pen orientation to the axis of predominant currents is critical.

4. The greater resolution of Gowen's model or any other modeling improvements (such as multiple settling velocities or complex topography) are secondary to the need for more defined criteria regarding wasteload, as discussed below.

The most settleable particles are the uneaten feed. However, lost feed ratios reported in the literature range from 1 to over 30 percent of the applied feed. Run 7 revealed the importance of the predicted wasteload in predicting deposition rates. Until more accurate criteria for wasteload are developed, which seems unlikely, less subtle improvements to the models are ineffective. The models may provide useful management tools, particularly when comparing alternative sites and pen configurations, or establishing best management practices to limit feed wastage.

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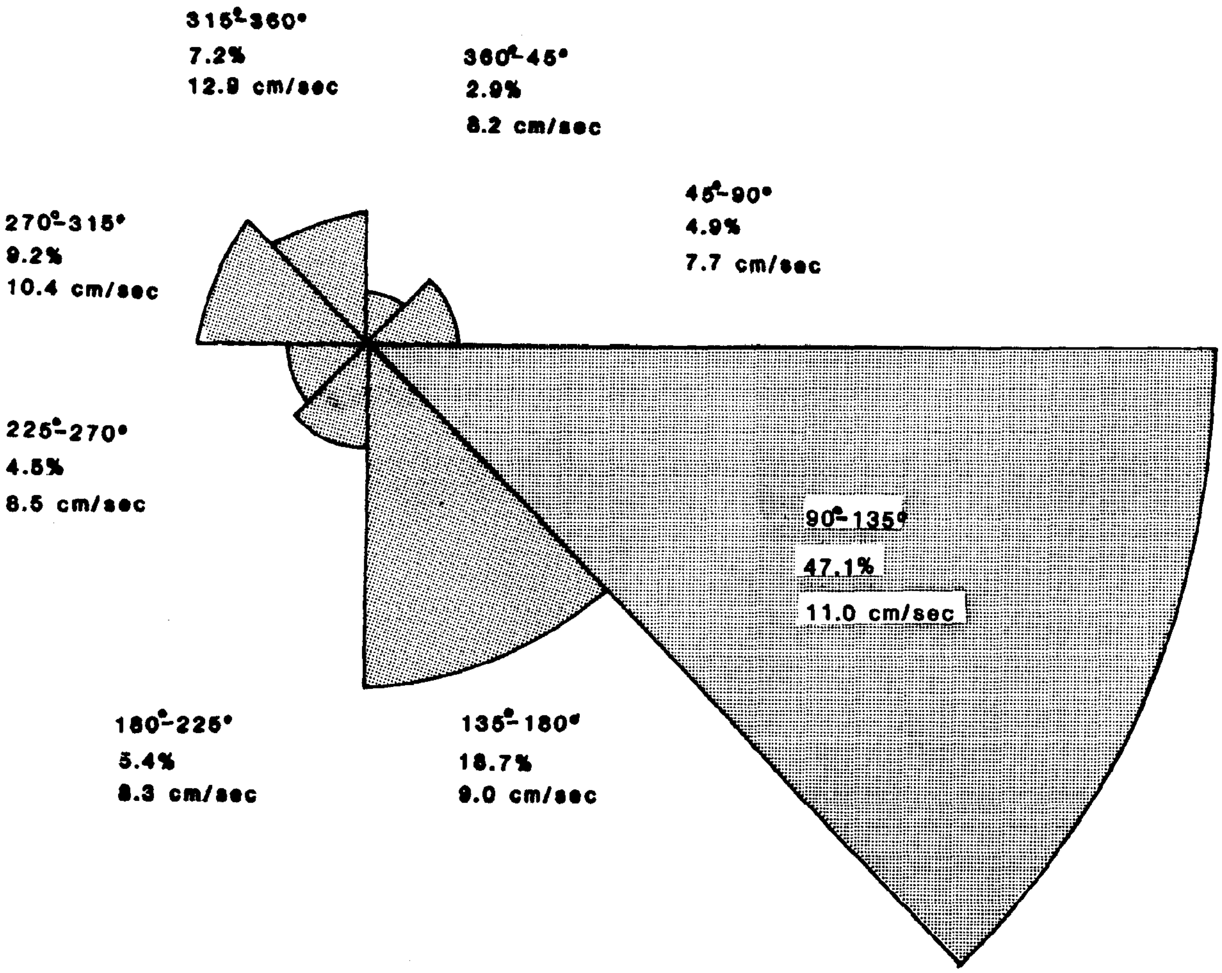
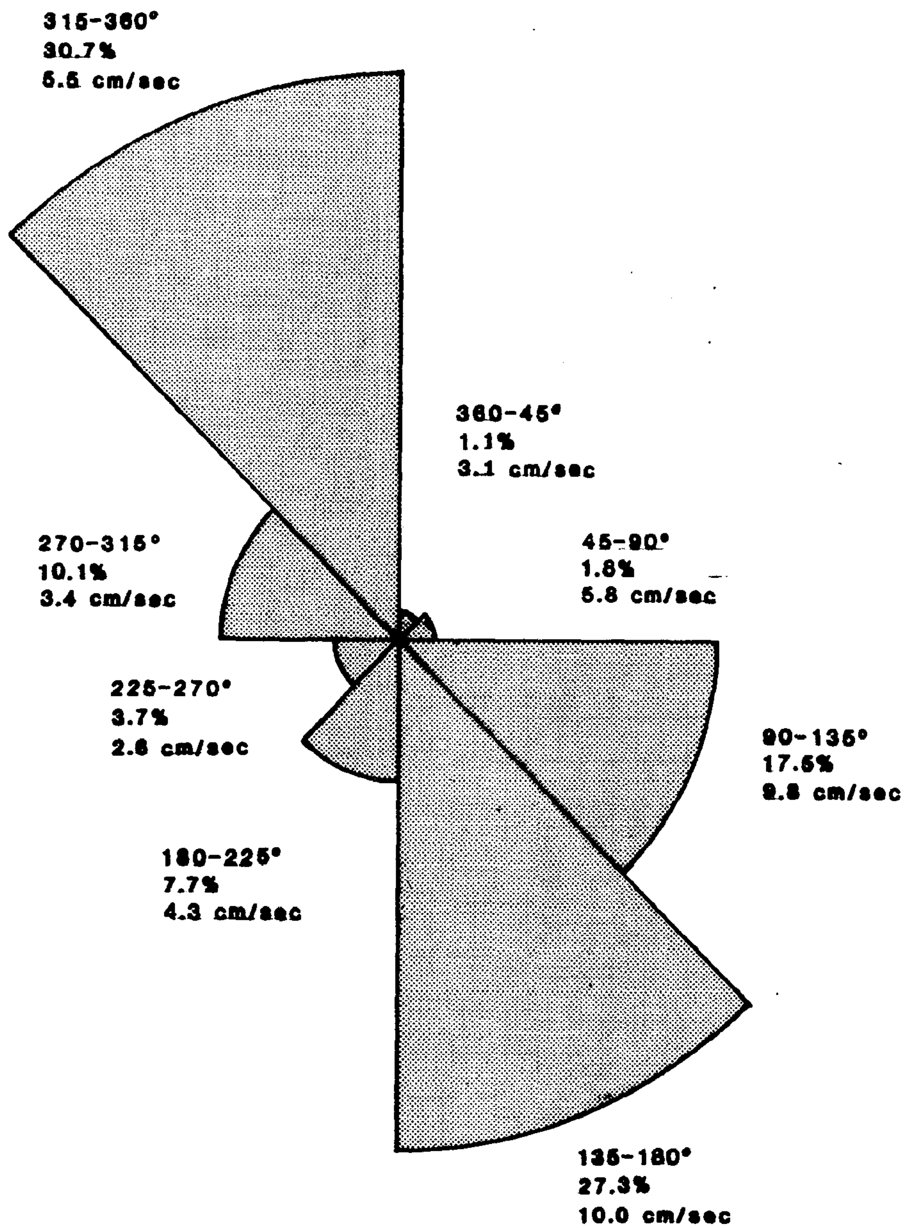


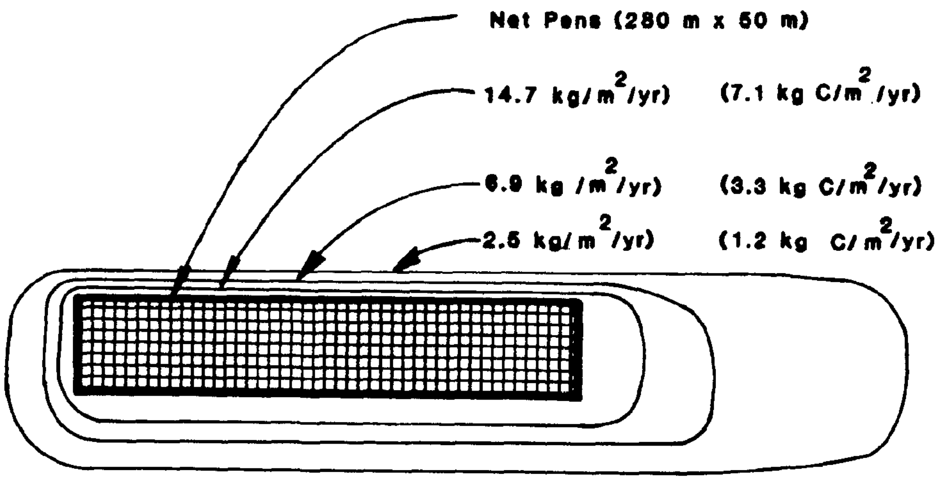
Note: Current Rose Indicates Percentage and Mean Speed of Currents Within Directional "Bins." Length of Rose is Proportional to Percentage.

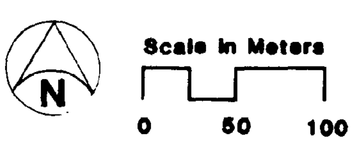
Figure 1:
Current Rose For
Clam Bay Site,
Meter F2053



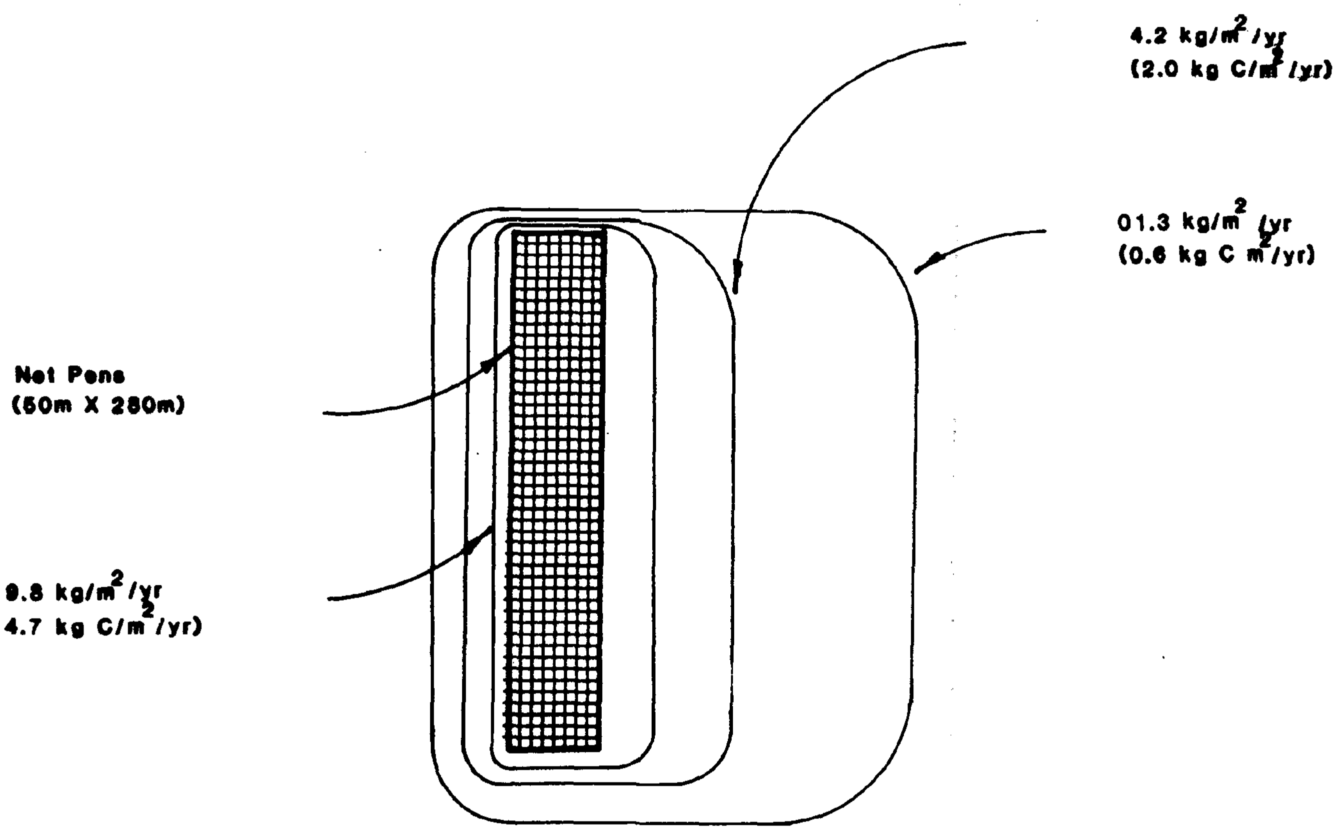
Note: Current Rose Indicates Percentage and Mean Speed of Currents Within Directional "Bins." Length of Rose is Proportional to Percentage.

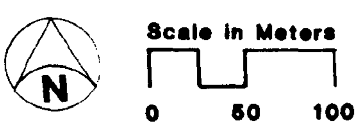
Figure 2:
Current Rose
For Squaxin Site,
Meter F2057



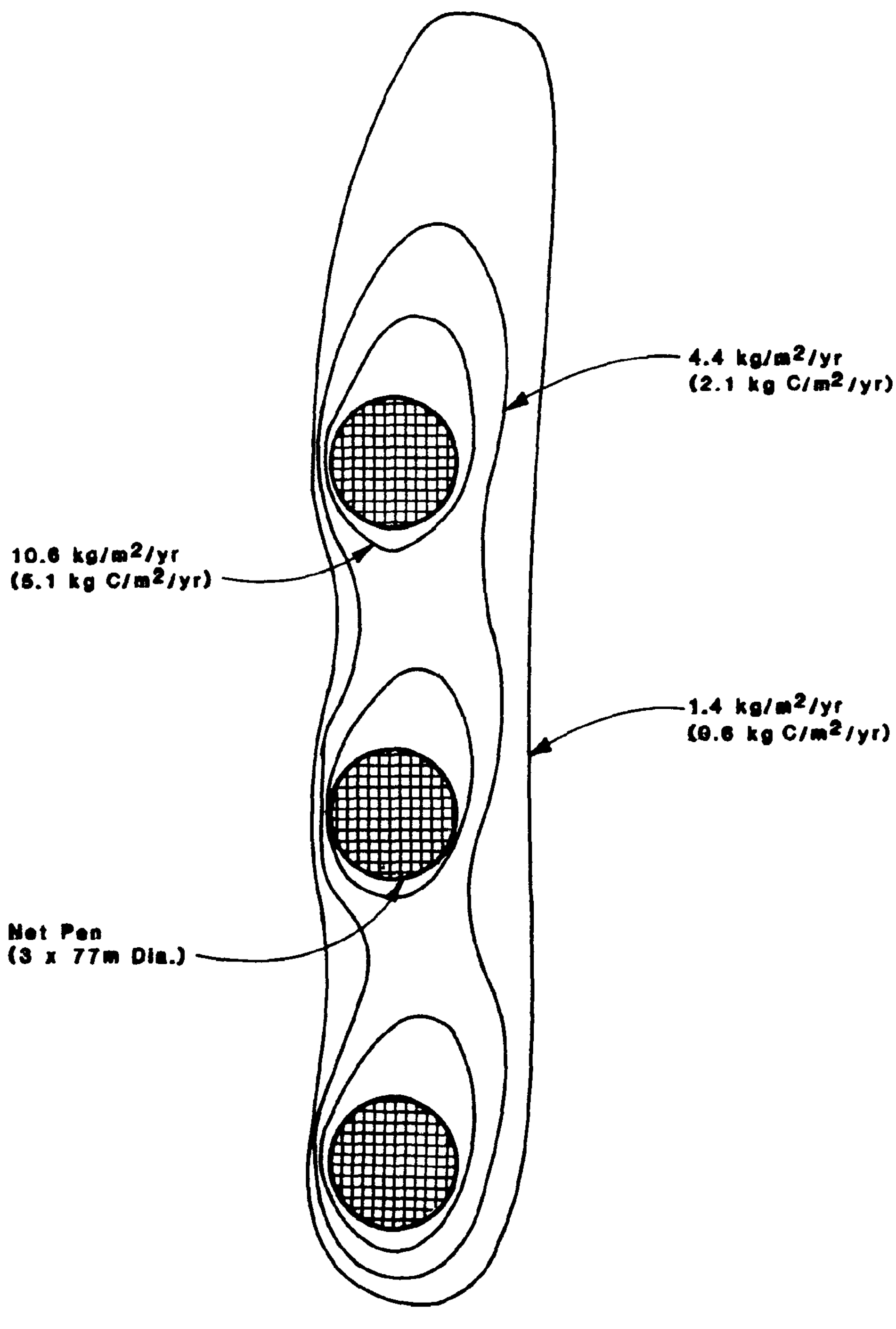


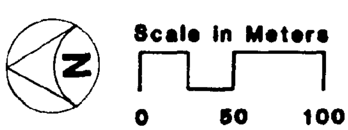
Run 1:
Clam Bay,
Existing Configuration



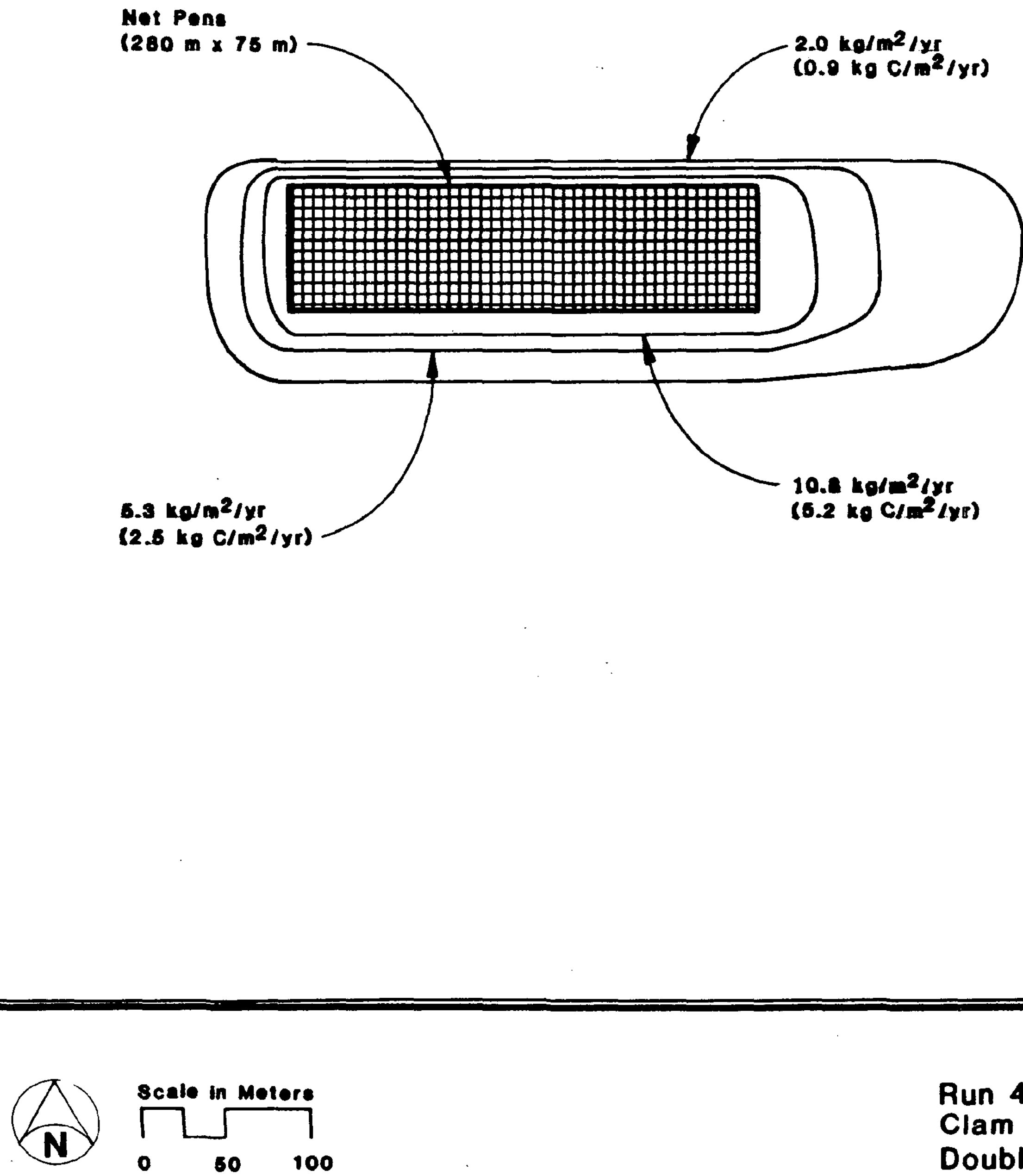


Run 2:
Clam Bay
Rotate 90°

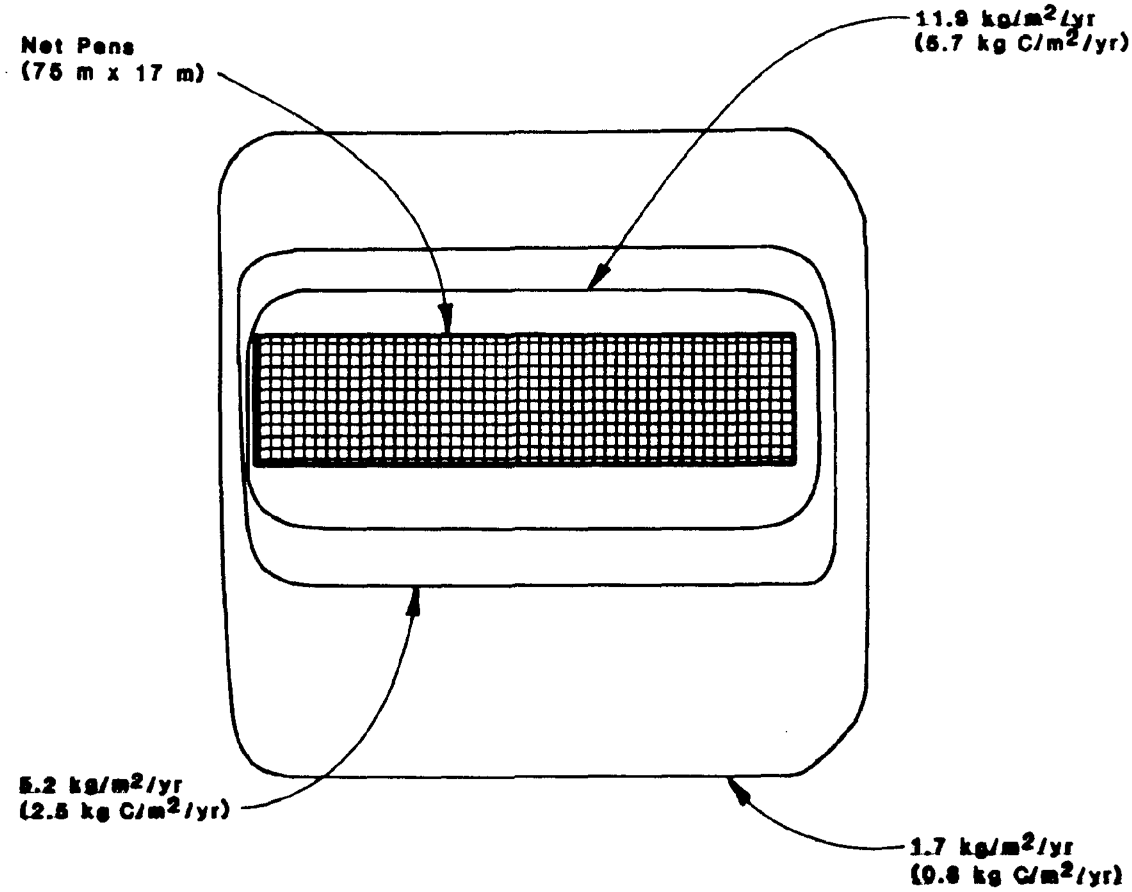


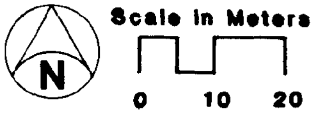


Run 3:
Clam Bay,
Round Pens

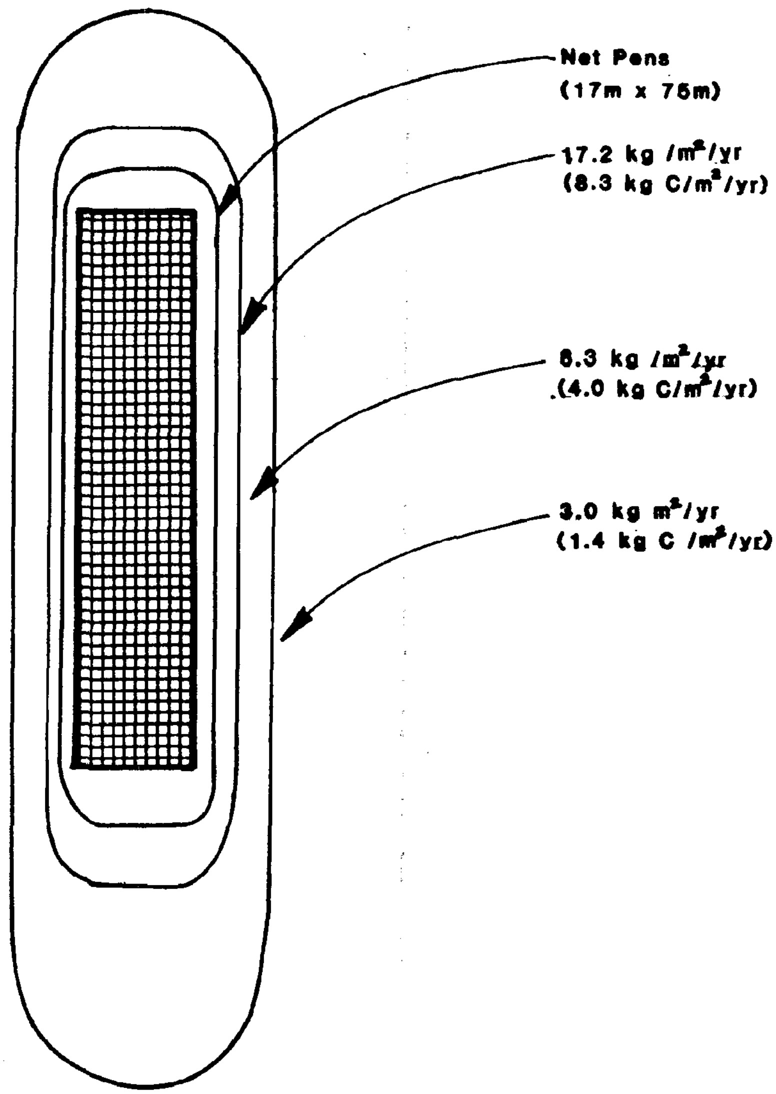


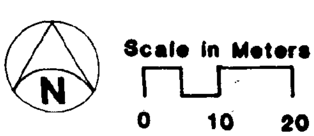
Run 4:
Clam Bay,
Double Wide Pens





Run 5:
Squaxin,
Existing Configuration





Run 6:
Squaxin Rotate 90°

APPENDIX C

PHYTOPLANKTON AND NUTRIENT STUDIES NEAR SALMON FISH FARMS AT SQUAXIN ISLAND, WASHINGTON

FINAL REPORT

PHYTOPLANKTON AND NUTRIENT STUDIES

NEAR SALMON NET-PENS

AT SQUAXIN ISLAND, WASHINGTON

by

John E. Rensel 1/
Rensel Associates
Seattle, Washington

for

The Washington Department of Fisheries
and the
Technical Appendices of the
Programmatic Environmental Impact Statement:

Fish Culture in Floating Net-pens

September 11, 1989

1/ Fisheries Scientist, American Fisheries Society Certified

Present Address: College of Ocean and Fisheries Sciences,
University of Washington, WH-10
Seattle, Washington 98195

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Abstract

The effects of a salmon net-pen farm on dissolved nutrient concentration, phytoplankton density and growth rate were investigated in a shallow passage of southern Puget Sound, near Squaxin Island, Washington. If background levels of dissolved nitrogen were sufficiently low for long enough periods, excreted nitrogen from the fish could enhance the growth of phytoplankton. The net-pen complex was the largest in western Washington located in surface waters that are depleted of dissolved nitrogen for at least some period of the time. Accordingly, the site constituted a "worst-available case" for net-pens in western Washington.

Two experiments were conducted. The first involved measurement of phytoplankton density and growth rates at the farm site during a period of maximum net-pen fish biomass and one month later during similar tidal and weather condition, but after release of 60% of the fish. Monitoring of reference stations at both ends of the passage, beyond the immediate area of the net-pens, was conducted to assess source water conditions and provide a comparison to the net-pen site.

The results of the first experiment suggest no consistant and significant effect of the net-pens, however natural variation of dissolved nitrogen concentrations confounded possible correlation between phytoplankton density/growth rate and the net-pens or reference stations. Moreover, only 2 of 12 samples were collected when major dissolved nutrients could have been limiting to phytoplankton growth. Therefore, most of the time phytoplankton cells were not limited by the ambient nitrogen concentration and addition of nitrogen from the pens could not have had a stimulating effect on their growth.

Although the timing and conditions were appropriate to maximize the effects of the net-pens on phytoplankton, and some patterns were observed, most of the statistical tests indicated that phytoplankton growth rate did not significantly vary among stations or times except during one monitoring period. The first experiment further serves to illustrates the complexity of monitoring phytoplankton in the field which involves a number of potentially rapid fluctuating variables.

The second type of experiment involved near field monitoring of nitrogen produced from the net-pens. During the period of maximum fish biomass, minor increases in dissolved nitrogen (NO_3+NO_2+NH_4^+) were seen downstream of the pens during one tidal period, but not during the next. Total ammonia was significantly elevated within the pens compared to ambient concentrations, but concentrations were well below the chronic exposure concentration for salmonids and other sensitive coldwater fish. At a distance of 30 m downstream approximately 80% of the ammonia had been was in the form of nitrate, presumably oxidized through microbial nitrification.

Introduction

Salmon reared in marine net-pens produce solid and dissolved wastes including various forms of nitrogen. Dissolved nitrogen wastes from salmon are as much as 60 to 90% ammonia, with lesser amounts of urea and amino acids (Stickney 1979). Nitrogen is the nutrient most likely to be limiting to the growth of marine phytoplankton. Therefore, the potential for localized nutrient enrichment and increased algal abundance near salmon farms exists, and will depend mainly on the total size of the farms in the restricted water body and existing hydrographic conditions (Gowen et al. 1985, Gowen and Bradbury 1987).

Nutrient limitation of surface waters is a key consideration of the State of Washington's Recommended Interim Guidelines for the Management of Salmon Net-pen Culture in Puget Sound (SAIC 1986). That document conservatively, but somewhat arbitrarily, designated the nutrient limitation status of sub-areas of Puget Sound based on a threshold of 0.1 mg/l, two and one-half times greater than one recent literature value of 0.04 mg/l (0.6 uM, URS 1986a). As discussed below, simple measurement of dissolved nitrogen concentrations is inadequate to determine if nitrogen is adequate for algal growth, N:P ratios also must be considered.

There are numerous difficulties in determining perturbations of phytoplankton from fish-farms or from other of man's activities. Foremost, as discussed above, once the net-pens are established, there is usually no adequate means to establish baseline conditions. Although nutrient uptake by phytoplankton may be rapid, there is a lag time of up to a day or so between the addition of nutrients and a measurable increase in phytoplankton biomass (Parsons et al. 1984). Knowledge of local hydrodynamic processes of dispersion, such as distance of tidal excursion, are required for interpretation of these types of data. Simply monitoring upstream and downstream of a net-pen farm site may reveal near-field nutrient effects, but may not be adequate to monitor the relatively slow response of phytoplankton populations to the increased nutrient concentrations. Monitoring of phytoplankton abundance and dynamics in the field is also difficult due to natural variations in time and space of the phytoplankton. A number of discrete or loosely interacting measures of water column ecology must be assessed, as no single measure provides all the necessary information.

Nitrogenous wastes from net-pen reared fish or other sources are unlikely to increase phytoplankton abundance in most of the main channels of Puget Sound since nitrogen is already in abundance (Collias and Lincoln 1977, Anderson et al. 1984, SAIC 1986). Accordingly, this study focused on a worst-available-case of nutrient enrichment from net-pens in what appeared to be nutrient-depleted waters, at least during some tidal, seasonal and weather conditions. To establish baseline conditions, the present study was conducted before and after the release of large numbers of fish at a public benefit, salmon rearing and release net-pen site. In addition to having spatially separate reference areas, "before fish release" water quality samples were used as the experimental data, and "after fish release" monitoring served as a baseline.

There have been relatively few attempts to monitor nutrient enrichment near salmon net-pens and even fewer studies of the effects upon phytoplankton dynamics. Prior studies of nutrients from net-pens strongly suggest there is little measurable effect beyond the immediate area of the pens (near-field). While nutrient concentrations are relatively easy to monitor, phytoplankton studies (far-field second and third order effects) are more difficult to conduct and have typically relied on measurement of chlorophyll a concentrations, the primary photosynthetic pigment in phytoplankton.

Prior Studies of Primary Productivity Near Net-pens

In one early study conducted in the Pacific northwest on this topic, Pease (1977) surmised that no measurable impact on phytoplankton populations occurred under worst-case conditions. The study area at Henderson Inlet, Washington had limited circulation during summer months, exacerbated by the net-pen site location within a shallow log dumping and storage area. Intense dinoflagellates blooms occurred at the site during the summer of 1974 which killed farmed salmon and prawns (Rensel and Prentice 1980). The 1974 blooms, which appeared to be exceptional in abundance, occurred throughout portions of southern Puget Sound and also killed salmon in net-pens at Squaxin Island. These conditions were not seen in the previous year at either Henderson Inlet (Snyder et al. 1974) or in several previous or one later year at Squaxin Island (Fraser 1976).

Pease (1977) found increased density of phytoplankton (chlorophyll a) during summer months with increasing distance into the log rafting area. The net-pens were located near the outer, seaward edge of the log rafting area. Reference areas (controls) were located in the main channel of Henderson Inlet, outside the log rafting area, and further inside the log rafting area. From my analysis of his monthly dissolved nitrate data (Table 5 and Fig. 8 of Pease 1977), it appears that nitrogen-depleted conditions could have occurred only in July when some of the samples had a concentration of less than 0.04 mg/l dissolved nitrogen and adequate phosphate concentrations. A generalized, inverse correlation between dissolved nutrient concentrations (nitrate and orthophosphate) and phytoplankton density was apparent over the entire summer period.

Phytoplankton standing crop during Pease's study was consistently greater at an reference station inside the log rafting area and at the net-pen site, compared to an outside, midchannel reference area in the open water of Henderson Inlet. However, Pease (1977) concluded that there were no abnormally high concentrations of phytoplankton anywhere in the area, and that phytoplankton activity throughout the inlet was unrelated to the net-pen rearing.

The second conclusion is possible, but neither supported or refuted by his data, as the inside reference area was too close (a few hundred feet) to the net-pens to be considered as separate and unaffected. Since water currents are weak and often imperceptible at the Henderson Inlet site, the inside log-rafting reference areas can not be considered as separate from the net-pen site, with regard to phytoplankton populations. These criticisms do not invalidate Pease's conclusions regarding other water quality conditions, but suggests that a greater standing stock of phytoplankton existed near the net-pens and that the effect of location and nutrient impact of the net-pens could not be sorted out given the experimental design.

Several years after removal of the Henderson Inlet facility Rensel (unpublished data, 1988) found that chlorophyll a concentrations in midchannel were about twice those found at the now vacant net-pen site, opposite the condition that prevailed throughout Pease's year long study (2.72 versus 1.71 ug Chl. a, SD = 0.273 and 0.412 respectively, n = 6). However, these samples were taken too late in the fall to be representative of optimum algal growing conditions and indicated relatively low phytoplankton density at both areas.

Recent studies in Scotland (Gowen et al. 1988) focused on phytoplankton density and growth rates in a restricted, fjordic sea-loch that had slow water movement (maximum flow of 16 cm sec^{-1}) and a single, large salmon net-pen farm. Additionally, water exchange into the 50 meter deep Loch Spelve is restricted by a 4 meter deep shallow sill. Study results indicate no measurable effect of the farm on phytoplankton density, although localized hypernutrification (elevated ammonia) was seasonally observed immediately around the net-pen farm. Carbon-14 isotope productivity data did not show any effect of the farm, although the authors felt that this portion of their study was based on insufficient data. In spite of slow water flow near the net-pens, the residency time of water was too brief to allow measurable increases in phytoplankton density or growth rates.

Study Site Selection

The criteria for selection of net-pen location for the present study involved finding a net-pen site in western Washington that was located in nutrient depleted waters, while still having relatively large fish production. Based on the authors experience with these facilities, the best site was located in Peale Passage, southern Puget Sound. This site, located just east of Squaxin Island (Fig. 1), is operated as a cooperative Washington Department of Fisheries and Squaxin Island Indian Tribal sponsored program. Coho (*Oncorhynchus kisutch*) and other species of salmon have been reared at the site since the early 1970's (STOWW 1974) and the nearby beaches have abundant littleneck clam and planted oyster populations. The Squaxin Island net-pens are presently the largest public benefit facility in Washington state and produces substantial numbers of fish for commercial and sport fisheries (Rensel et al. 1988).

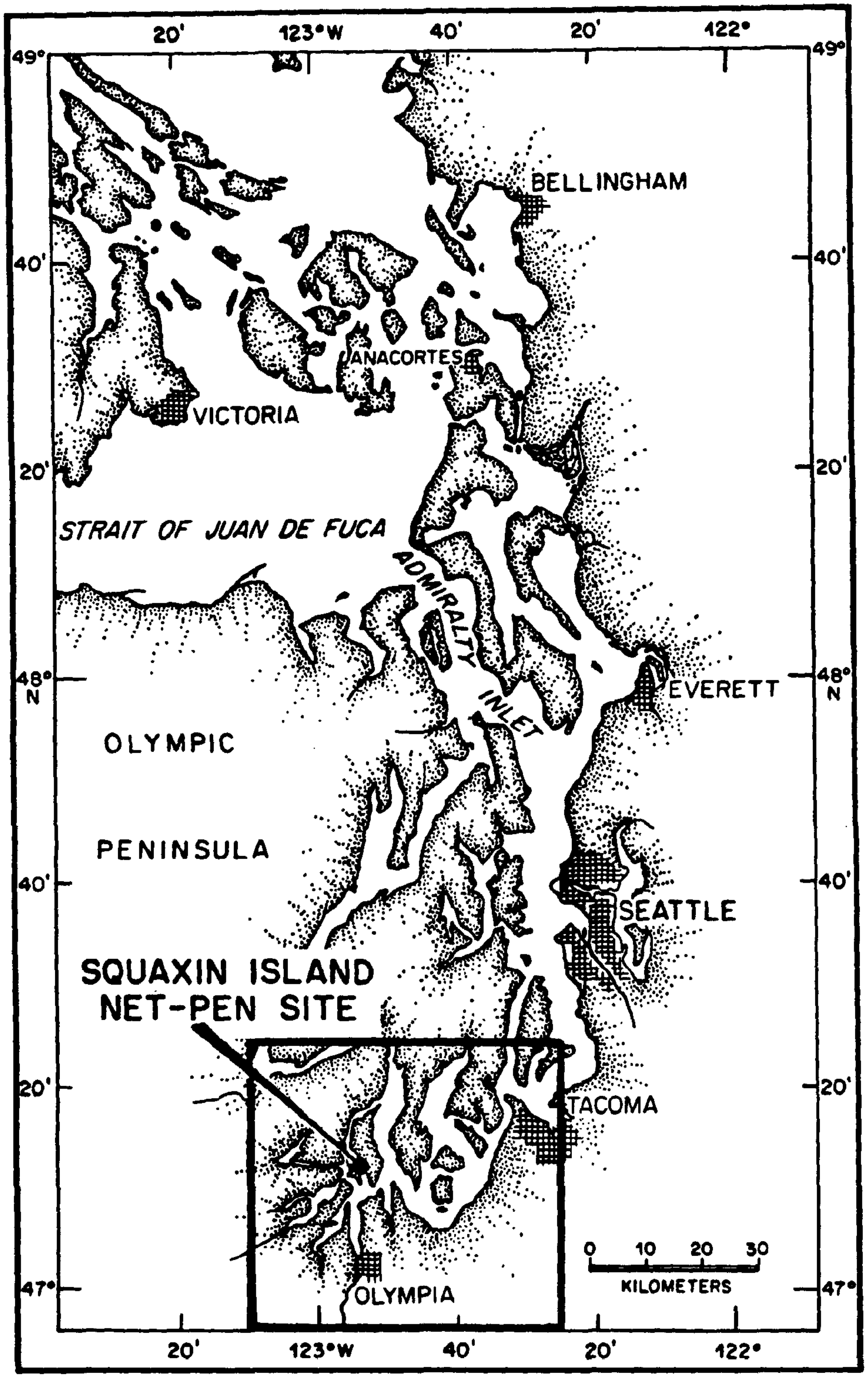


Figure 1. Map of the Puget Sound region with Squaxin Island net-pen site located in South Puget Sound within oulined box.

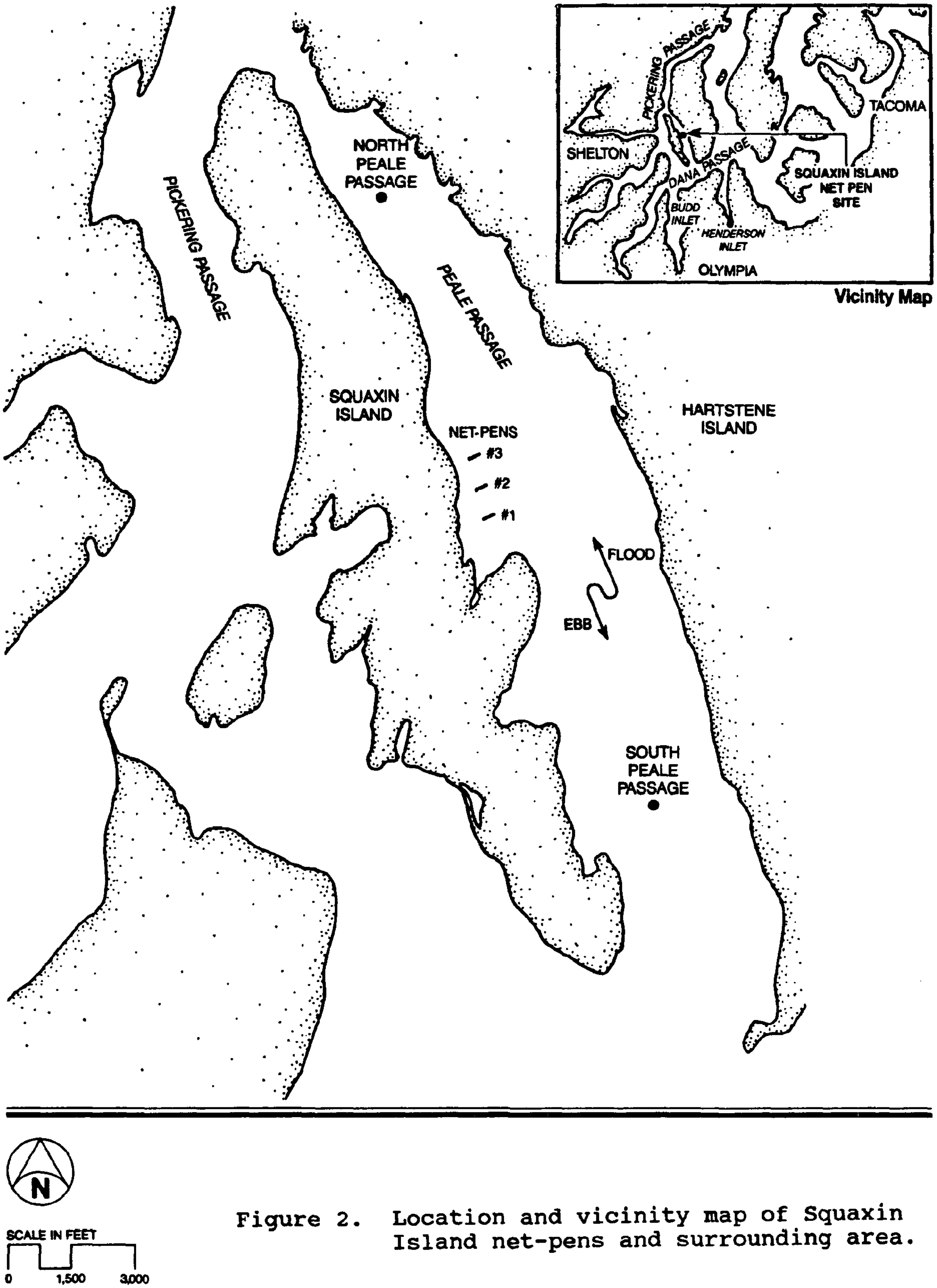


Figure 2. Location and vicinity map of Squaxin Island net-pens and surrounding area.

There are three adjacent sets of net-pens, two for delayed release of salmon and, in recent years, a third rearing facility to the north operated by the tribe for normal commercial purposes (pen system 3 in Fig. 2). All of the fish reared at the first two facilities are destined for release into Puget Sound, and are held in the net-pens for only a few months of the year after attaining smolt condition. This final condition allowed for comparison of water column conditions before and after fish release, during similar tidal conditions discussed later.

Site Description and Hydrography

Peale Passage is a shallow tidal channel connecting Dana Passage on the south and Pickering Passage to the north (Fig. 2). The Squaxin Island Indian reservation forms the west boundary of Peale Passage, Harstene Island the east boundary. The source waters for Peale Passage are relatively well-mixed by strong tidal currents, although only one year of sampling data were available for the Dana Passage sampling station (unpublished WDOE water quality data DNA001). These data indicate low dissolved nitrogen in surface waters occurred 15% of the period April to November. Pickering Passage data show low dissolved nitrogen in surface waters about 39% of the time (SAIC 1986).

Recent studies of circulation and nutrients in deep southern Puget Sound (URS 1986b) indicate that additional source waters for Peale Passage are the inlets at the west end of Dana Passage, especially Budd and Eld Inlets, due to clockwise circulation of surface and deeper waters in western Dana Passage. These inlets both exhibit strong vertical stratification and nutrient limitation during clement weather and undoubtedly influence Peale Passage surface waters at times during calm weather.

An early study of hydrographic conditions in southern Puget Sound measured vertical profiles of physicochemical parameters in Peale Passage on a few occasions (Oclay 1959). Moring (1973) noted that there was little background information concerning water quality in the Peale Passage area. His studies provide some basic information concerning conditions at the net-pen site. In subsequent years, fish culturists of the Squaxin Island Tribe collected additional information at the site that, combined with the earlier information, is adequate to characterize the vicinity. These data indicate that the area is well-mixed in the late fall to spring months but has a gradual thermal gradient and very minor salinity gradient in the clement weather periods of summer. There are no significant freshwater sources in Peale passage and no sharp discontinuities of water column characteristics.

Unpublished drogue (drift object) data collected for this study and recording current meter data collected for a related study (Weston and Gowen 1989) suggest that water passing through the net-pens does not exit Peale Passage on a moderate tide. This situation potentially could lead to an increased abundance of phytoplankton, since phytoplankton will rapidly assimilate dissolved nitrogen during periods of nitrogen depletion.

With an average depth of about 5.0 meters at mean lower low water (MLLW), depths in the vicinity of the net-pen site are shallow compared to other existing net-pens in Western Washington. Mean water current velocity near the most northern set of net-pens is about 6 to 7 cm sec^{-1} with a net directional flow to the south (Weston and Gowen 1989). Currents diminish an undetermined amount in the vicinity of the other two net-pens and may be affected by the presence of a small cove that tends to slow water movement and form a gyre, particularly on the flood tide (unpublished survey data of B. Wood, Squaxin Island Tribe, 1982).

Although no historical nitrogen data were available from Peale Passage, two days prior to the first sampling date of this study I found dissolved nitrogen concentrations less than 0.04 mg/l, and a dissolved nitrogen to phosphorus (N:P) ratio of about 1:1, indicative of nitrogen limitation. Use of a single numerical value of dissolved nitrogen may be misleading for representation of the actual threshold of nutrient depletion (Welch 1980). Examination of both the dissolved nutrient concentration and the N:P ratio, sequentially, is more useful in determining if nitrogen depletion exists. Recent studies in nearby Budd Inlet suggested that nutrient limitation in surface waters occurred during summer months when the concentration of dissolved nitrogen was less than 0.04 mg/l and dissolved molecular N:P ratios were 5 to 1 or less (URS 1986a).

Table 1. Sampling parameters and number of replicates per depth.

	^{14}Carbon isotope	Chlorophyll *a*	Dissolved nutrients	Dissolved oxygen	Secchi Disc	Temper.-Salinity	Phytop. counts	Total N & P
Experiment A-1: pens versus reference areas, May 25th, before fish release								
Low Tide	3	1	1	1	1	1	-	1
High Tide	3	1	1	1	1	1	1	1
Experiment A-2: pens versus reference areas, June 21st, after fish release								
Low Tide	3	3	3	1	1	1	1	1
High Tide	3	3	3	1	1	1	1	1
Experiment B: upstream and downstream of pens, May 25th								
mid-flood	-	-	3	1	1	-	-	3
early ebb	-	-	3	3	1	-	-	1

Codes: ^{14}Carbon isotope = primary productivity assessment, phyto. counts = microscope identification and enumeration of phytoplankton, total N and P = total nitrogen and phosphorus (sum of dissolved and particulate) Total N and P from center of the net-pens only on ebb tide, experiment B. pH was sampled concurrent to collection of nutrient samples.

Experimental Design

Two types of experiments were conducted. The goal of experiment A was to investigate rates of primary productivity near the net-pens and at reference areas, as measured by the uptake of radiocarbon isotope C-14. Reference area stations were selected to be remote enough from the net-pens to avoid having waters that had passed through the net-pens on any single, moderate amplitude tide. Sampling was conducted during morning and early afternoon hours that coincided with the early and late portions of the flood tide, essentially low and high tide. The experiment was conducted before and after release of most of the delayed-release fish (experiments A-1 and A-2, respectively), about a month apart, during similar tidal exchange and timing. Both dates had relatively calm, warm weather and were during the peak algal growing season in Puget Sound (Winter et al. 1975, URS 1986a). Other direct measures of phytoplankton density (chlorophyll a and species cell counts for relative abundance) as well as indirect, surrogate measures (Secchi disk depth and dissolved oxygen concentration) were made as time allowed.

During sampling in late May 1988, the three sets of net-pens had a total of 118,600 kg of fish distributed 38% within system number 1, 45% in system number 2 and 17% in system number 3. Most of the fish in system one and two were released in early June. During the second sampling date in late June there was approximately 47,200 kg of fish in the net-pens, 55% within system number three and 45% in system two.

Experiment B was an assessment of water quality upstream and downstream of the net-pens, similar to nutrient monitoring described in the Interim Guidelines (SAIC 1986). The monitoring was conducted at low and high tide in late May, before release of the fish. The goal of experiment B was to monitor the near field effect of the net-pens on nutrient and ammonia concentrations. Table 1 summarizes the measurements and replication conducted for experiment A and B.

Worst-possible-case conditions were ensured by timing the experiments during a period with: the greatest amount of fish in the pens (experiment A-1) and with relatively small tidal exchange. The mean tide for nearby Dofflemeyer Point is 10.4 feet, and the diurnal range is 14.4 feet. Sampling on May 25 and June 21st was conducted on the beginning and end of 6.3 and 4.9 foot flood tides, respectively.

Methods

Water velocity at the net-pen site was measured with a Scientific Instruments Price Meter, fitted with an Swoffer optical sensor and remote, digital readout unit. Surface drift sticks and 2 meter deep drogues were used to monitor current direction immediately downstream of the net-pens. Salinity and temperature were measured with a YSI SCT-33 meter carefully calibrated to standard seawater solution. All water samples were collected with a 2 liter Scott-Richards sampling bottle. Dissolved oxygen was measured by a modified Winkler titration method with an accuracy of 0.02 mg/l. pH was recorded in the field using a VWR model 55 probe. Chlorophyll a samples were collected by filtering 50 ml of water through Whatman GF/F filters. Filters were folded, packaged and iced for analysis later the next day.

Nutrient samples were collected in acid washed and sample-water rinsed, polyethelene bottles, iced and frozen later the same day. No filtering or acidification was conducted to avoid introduction of broken cells and other artifacts, and to avoid destruction of nitrite (APHA 1985). This is standard research methodology used for dissolved nitrogen analysis of seawater samples at the University of Washington.

Determination of dissolved nitrogen (defined as NO_3+NO_2+NH_4^+) and orthophosphate was conducted at the University of Washington Routine Chemistry Laboratory using a technicon autoanalyzer. Dissolved nutrient results were reported both as mg/l (ppm), for ease of comparison to Weston (1986), as well as ug-at./l units (micromoles also referred to as uM) for comparison to other of other studies using such ratios. Identification and enumeration of larger phytoplankton (greater than 5-10 microns) was conducted by an experienced phycologist using sedimentation chambers to concentrate samples and an inverted microscope (Unesco 1978).

Relative rates of phytoplankton production were estimated using a modification of the carbon 14 productivity method (Steemann Nielsen 1952), using water from the same water bottle cast that provided chlorophyll a, nutrients and other measures mentioned above. Samples were collected, during the morning and afternoon, from 2 m at three sites: directly next to the net-pens and at the north and south entrances to Peale Passage (Fig. 2). Triplicate 120 ml samples were put into acid-cleaned 125 ml BOD bottles and transported in the dark to the net-pens for incubation.

On May 25, 1988, 1.1 ml of the ^{14}C stock (20 uCi/ml $NaHCO_3$ solution) was added to each sample, and then 100 ul was immediately removed and placed into a liquid scintillation cocktail containing phenethylamine for total activity determination. The BOD bottles were incubated next to the pens at 2 m depth within 20 minutes of sample water collection. Care was taken to insure that the incubating samples were never shaded by the pens. At the end of the incubation period (5.67 hrs for the morning samples and 2.67 for the afternoon samples), duplicate 20 ml aliquots were removed from each BOD bottle and placed into a glass scintillation vial containing 1.8 ml of a 37% formalin. Upon return to the laboratory, the formalin-killed aliquots were filtered onto glass fiber filters (Whatman GF/F), fumed over 12 N HCL for 15 seconds, and placed in scintillation vials. Seven ml of liquid scintillation solution was added to the vial, and shaken overnight. The samples were counted in a Beckman LS1800 liquid scintillation counter for 15 minutes. Carbon uptake was calculated according to Strickland and Parsons, (1968). Reported values are not corrected for time-zero controls or dark bottles.

On June 21, 1988, the same initial procedures were followed. Additionally, single aliquots for time zero controls were removed and placed into glass liquid scintillation vials containing 1 ml 6 N HCL. At the end of sample bottle incubation, duplicate 5 ml aliquots were removed from each BOD bottle and placed into glass scintillation vials containing 1 ml of 6 N HCL. Upon returning to the laboratory, 8 ml of liquid scintillation solution was added to the vials, and they were shaken overnight. The samples were counted in a Beckman LS1800 liquid scintillation counter for 15 minutes. Reported values were corrected for time zero controls but not for dark bottles.

Statistical analysis of hydrographic data utilized one way and two-way analysis of variance and T-test procedures (Zar 1984).

Results

Experiment A

On sampling dates before and after the fish were released all stations had weak thermal stratification with little difference between the salinity at the surface and bottom (Tables 2 and 3). The highest water temperatures usually occurred at the southern entry to Peale Passage, not at the mid-channel areas near the net-pens. No trends in dissolved oxygen concentrations were seen on either sampling date. Secchi disk values (water transparency) were slightly lower at the net-pen site on both sampling dates.

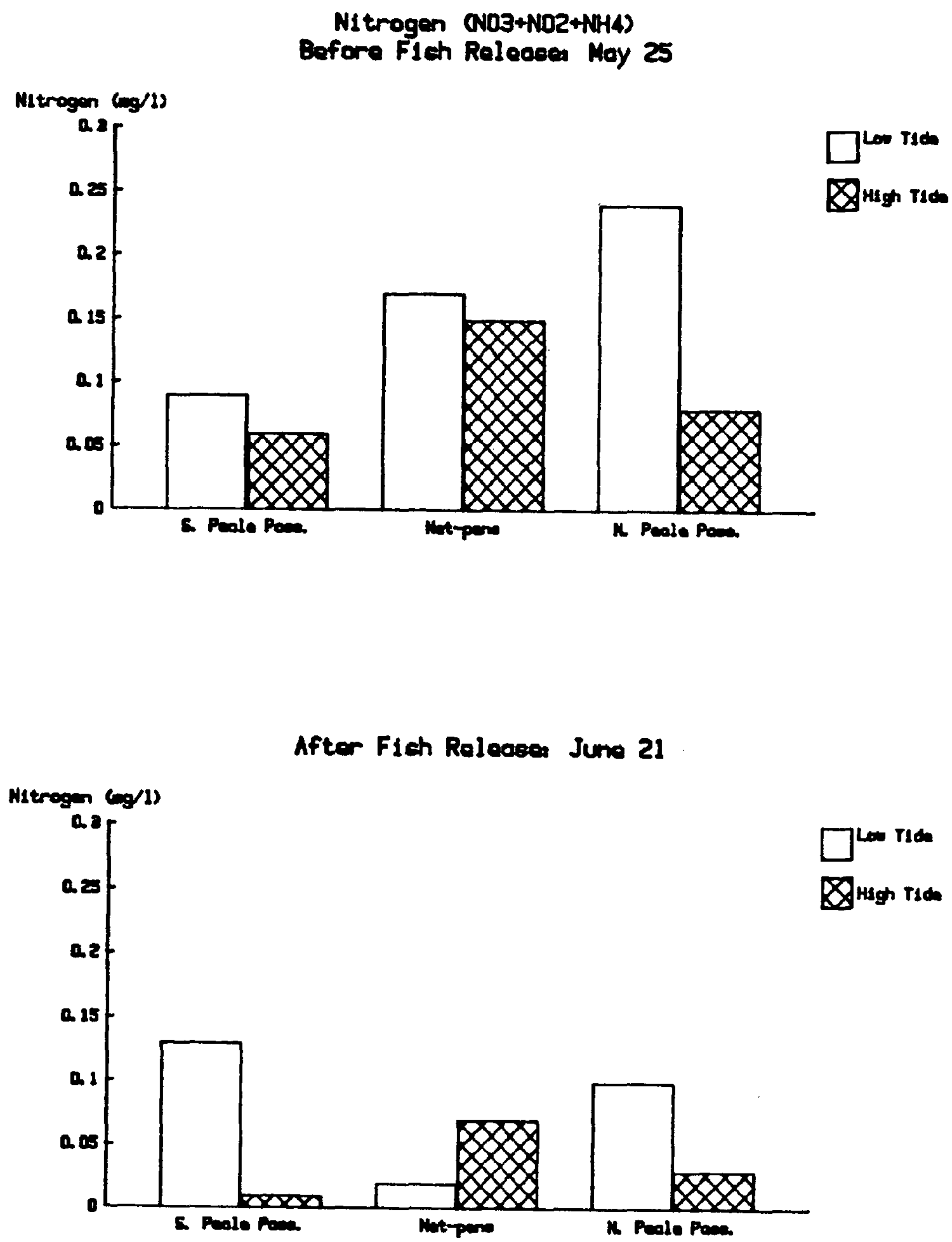


Figure 3. Dissolved nitrogen concentration before fish release (top, Fig. 3a) and after most of the fish were released (Fig. 3b). Standard deviation bars are omitted due to the very small amount of variance.

Table 2. Partial results of experiment A-1 from May 25, 1988. Sampling times noted for each tide.

Station	Depth (m)	Temp. (C)	Sal. PPT	Secchi Disk (m)	Dissolved Oxygen mg/l	Percent Oxygen Saturation	Chl. a ug/l	Dissolved Nitrogen mg/l
LOW TIDE: 0940-1030 hours								
South	0	13.5	28.9	5.8				
Peale	2	13.5	29.0		10.8	124%	6.81	0.09
Passage	5	12.0	29.0					
	10	11.4	29.1					
Net-	0	13.1	29.0	3.6				
Pen	2	12.2	29.0		8.7	98%	23.91	0.17
Site	5	11.4	29.0					
North	0	12.1	28.9	4.0				
Peale	2	12.1	28.9		10.3	116%	6.52	0.24
Passage	5	11.9	29.1					
HIGH TIDE: 1305-1400 hours								
South	0	15.1	28.1	4.5				
Peale	2	13.5	28.4		13.7	158%	13.58	0.06
Passage	5	12.5	28.7					
	10	11.1	29.7		14.1	155%	15.25	0.70
Net-	0	13.1	29.0	3.5				
Pen	2	12.2	29.0		12.1	134%	15.56	0.15
Site	5	11.4	29.0					
North	0	13.6	29.0	3.9				
Peale	2	12.9	29.0		10.4	119%	9.76	0.08
Passage	5	12.1	29.0					

Table 3. Partial results of experiment A-2 from June 21, 1988. Standard deviation shown in parenthesis. Sampling times shown for each tide.

Station	Depth (m)	Temp. (C)	Sal. (PPT)	Secchi Disk (m)	Dissolved Oxygen (mg/l)	Oxygen Saturation Percent	Chl. a (ug/l)	Dissolved Nitrogen (mg/l)
<u>LOW TIDE</u>: 0830-0928 hours								
South	0	14.9	29.2	3.9				
Peale	2	13.8	29.1		9.6	116%	6.99	0.13
Passage	5	13.0	29.0				(0.082)	(0.019)
	10	12.6	29.0					
Net-	0	15.1	29.3	3.8				
Pen	2	14.9	29.0		12.0	143%	4.73	0.02
Site	5	14.1	28.8				(0.759)	(0.004)
North	0	15.0	29.0	3.4				
Peale	2	14.4	28.9		9.6	129%	6.84	0.10
Passage							(0.798)	(0.005)
	5	13.8	28.7					
<u>HIGH TIDE</u>: 1209-1310 hours								
South	0	15.3	29.0	3.7				
Peale	2	14.8	29.0		11.8	141%	3.95	0.01
Passage	5	13.5	29.0				(1.777)	(0.001)
	10	12.8	29.0					0.49
								(---)
Net-	0	17.5	29.1	3.0				
Pen	2	15.0	28.8		12.1	144%	4.20	0.07
Site	5	14.1	29.0				(0.950)	(0.006)
	8	13.8	28.9					
North	0	16.4	28.5	3.5				
Peale	2	15.2	28.5		11.0	131%	5.47	0.03
Passage	5	14.0	28.7				(1.800)	(0.006)
	10	13.6	28.8					

Table 4. Dissolved nitrogen and phosphorus concentration, molecular nitrogen to phosphate (N:P) ratios and probable nitrogen limitation of diatom phytoplankton. Threshold of nitrogen limitation for diatoms is about 0.04 mg/l dissolved nitrogen or expressed in molecular value, about 0.65 ug-at/l. If dissolved N was <0.65 ug-at/l and N:P ratio < 5, nitrogen limitation was probable. Phosphorus limitation could occur at N:P ratios >10-15.

Site	Concentration in ug-at/l Dissolved N	Dissolved P	N:P Ratio (atomic)	Probable Nitrogen Limitation
Experiment A-1: before fish release on May 25, 1988.				
Low Tide				
south Peale				no
net-pen site	3.09	1.20	2.6	no
north Peale	4.37	1.15	3.8	no
High Tide				
south Peale	1.24	0.87	1.4	no
net-pen site	1.85	1.05	1.7	no
north Peale	1.24	0.87	1.4	no
Experiment A-2: after fish release on June 21, 1988.				
Low Tide				
south Peale	0.06	0.86	0.1	yes
net-pen site	3.21	1.07	3.0	no
north Peale	0.87	1.02	0.8	no
High Tide				
south Peale	3.11	1.10	2.8	no
net-pen site	0.54	0.94	0.6	yes
north Peale	2.08	1.23	1.7	no

Nutrients: In general, dissolved nitrogen concentrations (previously defined as NO_3+NO_2+NH_4^+) were less after fish release than before at all three sampling stations (Fig. 3, tables 2 and 3). Nutrient limitation of diatoms growth was probably not in effect in any of the samples collected before the fish were released, due to the relatively high ambient dissolved nitrogen concentration (> 0.04 mg/l threshold value for diatom growth limitation previously discussed, table 4).

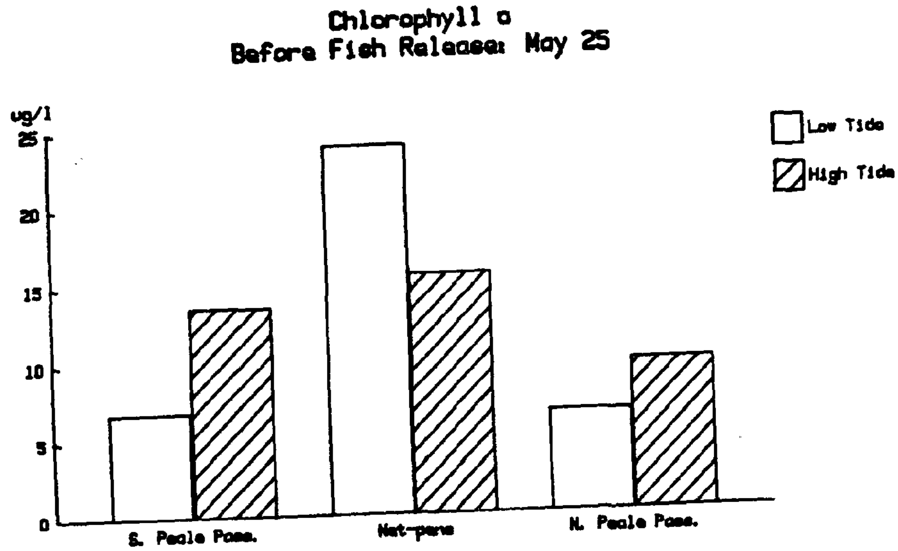
Large differences were noted between the concentration of dissolved nitrogen at low and high tides for 4 of the 6 bar clusters in figure 3 and proved significant for the period after fish release ($p < 0.05$). Significance testing could not be acertained for the period before fish release due to lack of sample replication, but there was likely no difference at the net-pen site or at the south Peale station. This judgement is based on the excellent precision normally seen in nitrogen measurements conducted at the university's laboratory, as found in the June samples discussed below.

It is important to note that the between tidal variation was obviously unrelated to the net-pens, as it occurred at both the net-pens and the reference stations, at least part of the time. Since experiment A was predicated upon having nutrient limitation at all times, this result complicates the later interpretation of of radiocarbon productivity measurements. Changes in productivity could have been related to fluctuating nutrient concentrations, masking any effect that the net-pens would produce. There are, however, some important bits of information to be gleaned from the rest of this experiment.

There were some possible trends of nutrient concentration, such as a a gradient of increasing dissolved nitrogen from south to north at low tide before the fish release, but without further sampling between stations, it is not possible to conclude that the trend was real. Considered alone, dissolved nitrogen to phosphorus ratios (table 4) were indicative of nitrogen limitation (Redfield 1958, Ryther and Dunstad 1971, McCarthy 1980, URS 1986a), but the apparent imbalance is totally overshadowed by the absolute concentrations of nitrogen, which indicated no nitrogen limitation before fish release and only partly after the fish release.

The precision of the measurements was very good since variation among replicates nitrogen samples was very small. The variation among replicates so small that it was graphically impossible to represent 5 of the 6 error bars in figure 3b.

Chlorophyll a: In general, increased chlorophyll a concentrations were observed at all stations before fish release, matching the greater concentration of dissolved nitrogen at that time (compare Figs. 3 and 4). The concentration of chlorophyll a was much greater than reference stations at the net-pens at low tide on May 25, but only slightly greater by high tide (Fig. 4a). Since replicates were not obtained, statistical significance is not known. However, the concentration at low tide near the net-pens was nearly four times



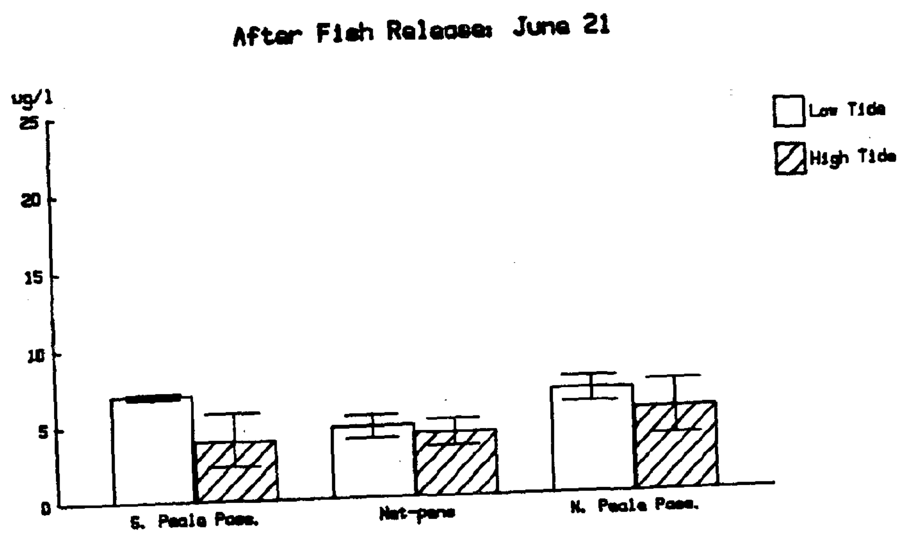


Figure 4. Chlorophyll a concentration before fish release (top. Fig. 4a) and after most of the fish were released (bottom, Fig. 4b).

greater than the reference areas and likely to be significantly greater.

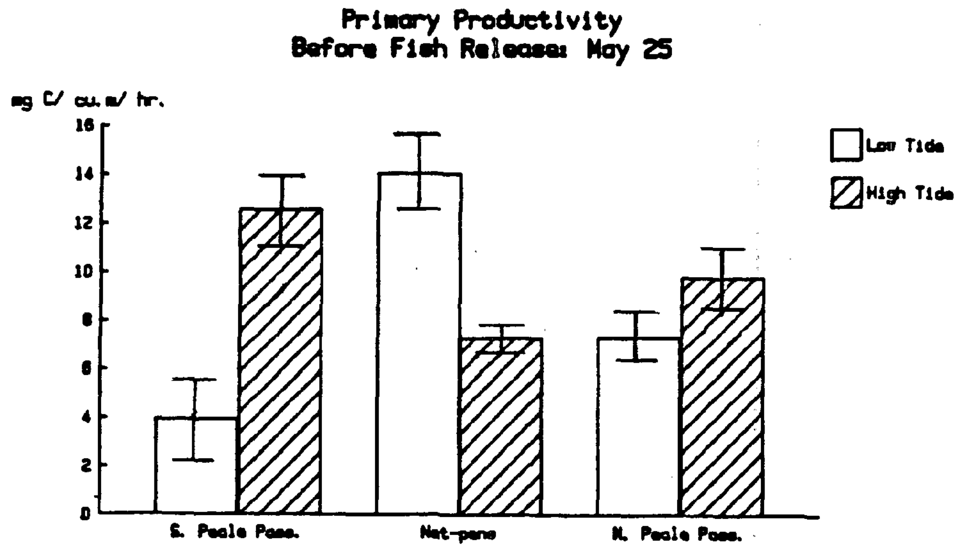
After most of the fish were released, on June 21 (Fig. 4b), there was significantly less chlorophyll a ($p < 0.05$) at the net-pen site, compared to reference stations at low tide. However, by high tide no statistical differences were apparent as suggested by the overlapping standard deviation bars of that tide shown in figure 4b. These results suggest that tidal related natural variation of phytoplankton density occurred at the net-pen site.

Primary Productivity: Statistical analyses of the raw data (appendices a-1 and A-2) indicated that there were significant differences in primary productivity between the net-pen site and the reference areas at low tide, but not at high tide ($p < 0.05$). Due to methodological differences in processing the samples, there could be no comparison of absolute values between sampling dates.

A similar general trends among stations and between tides was apparent as seen in figures 5a and 5b. Increased productivity near the net-pens during the morning low tide was noted on both dates. Since there werer few statistical differences, this trend can only be noted and not interpreted as significant. Note that standard error bars were shown here, to save space, not standard deviation bars. Standard error is the standard deviation divided by the square root of the number of replicate measures. If standard deviation was shown on figure 5b, there would be greater overlap of bars.

There were no statistical differences among stations or times of sampling on June 21. Variance within replicate samples was fairly high, as is common for radiocarbon data from the field. Some of the replicate samples could have contained statistical outliers (see replicate values in appendix table A-2, pens). However, this data was not excluded from the analysis.

The results of the productivity experiment indicate significant tidally related variation at the net-pens before the fish were released, although rates of primary productivity were not significantly different among stations. On there own, these data suggest that the net-pens did not produce a significant effect, but since dissolved nitrogen concentrations and chlorophyll a results varied significantly among some of the stations and times, it is impossible to conclusively state that there was no effect. This is typical in all field studies, where correlative data is the norm.



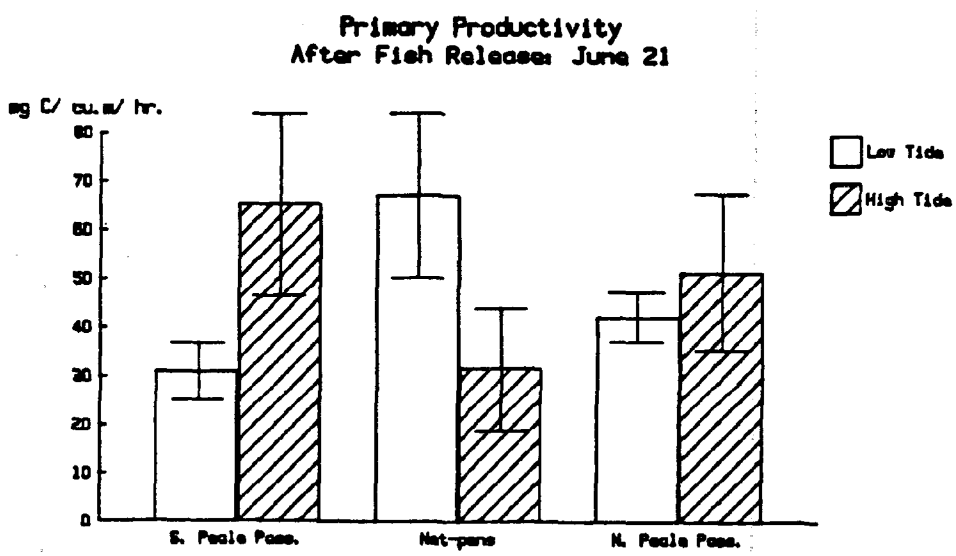


Figure 5. Primary productivity before fish release (top, Fig. 5a) and after most of the fish were released (bottom, Fig. 5b). Standard error bars are shown where appropriate. N = 6 for each station.

Cell Counts: A summary of the species assemblage present during portions of the study is shown in table 5. On both sampling dates diatoms were by far the dominate phytoplankton. During the May sampling *Coscinodiscus spp.* and *Thalassiosira spp.*, common chain forming species were prevalent. By late June *Chaetoceros*, also a very common diatom group, were most abundant. The *Chaetoceros spp.* present were members of the subgenus *Hyalochaete*, thought not to be directly responsible for fish kills in net-pens in the past as have been members of the subgenus *Phaeoceros* (Gaines and Taylor 1986). However, reports from Canada (Bell et al. 1974) and studies in Washington State (Rensel et al. 1989), indicate that these species may contribute to mortality of net-pen salmon when abundant. There were not enough phytoplankton samples to make a rigorous comparison between tide stage or to other environmental factors. However, the slightly greater number of cells at the net-pens versus the reference station on May 25 appeared to correlate with nutrient and chlorophyll *a* values at high tide. The net-pen site had greater counts at high tide of June 21, which correlated with increased nutrient concentration, primary and specific productivity, but not with chlorophyll *a* concentration.

Table 5. Summary of cell counts from 2 m depth in cells per ml.

BEFORE FISH RELEASE: May 25, 1350-1420 hr.

	S. Peale	Pen site	N. Peale
Chaetoceros Hyalochaete spp.	51	0	not
Coscinodiscus ongusta-lineata	118	191	sampled
Thalassiosira spp.	24	16	
total diatoms	231	278	
total dinoflagellates	22	131	
--------------------	----	----	
total phytoplankton (c/ml)	536	664	

AFTER FISH RELEASE: June 21, 1220-1310 hr.

	S. Peale	Pen site	N. Peale
Chaetoceros Hyalochaete spp.	536	1,639	740
Skeletonema costatum	6	25	80
Misc. pennate diatoms	2	59	22
total diatoms	645	1,825	952
total dinoflagellates	28	52	52
--------------------	----	----	----
total phytoplankton (c/ml)	806	2,069	1,109

Experiment B

During the morning flood tide, the concentration of dissolved nitrogen immediately upstream of the net-pens averaged 0.07 mg/l (table 6). The dissolved nitrogen (DN) was composed of nitrate (78%) and ammonia (22%). Just downstream of the net-pens, the concentration of dissolved nitrogen had doubled to 0.15 mg/l, which was significantly greater than upstream ($p < 0.005$). However, most of the dissolved nitrogen was in the form of nitrate (NO_3 = 86% of DN), not ammonia (NH_4^+ = 12% of DN). A similar picture emerges if the data is viewed on a gram atom weight basis; the downstream nitrate was about 2.5 times greater than the ambient concentration. There was no statistical difference in the concentration of ammonia during this tide (on either unit basis) from upstream to downstream, but nitrate was significantly greater downstream ($p < 0.001$).

Total ammonia concentration in the plume of the net-pen during the morning flood averaged 0.0163 mg/l which is equivalent to an un-ionized ammonia concentration of 0.00037 mg/l at pH 8 and temperature 13 C. The EPA (1986) chronic exposure criteria (four day average concentration) for un-ionized ammonia under these conditions is 0.030 mg/l, about 80 times greater than the concentration observed downstream from the net-pens.

During the early portions of the ebb tide, the concentration of total dissolved nitrogen was significantly greater within the net-pens compared to upstream values ($p < 0.001$ for NH_4^+ and NO_3, $p < 0.005$ for NO_2). However, there was no significant difference in the upstream and downstream values of total dissolved nitrogen. Within that total, there was a significant increase in the concentration of ammonia (table 7). The proportion of toxic, un-ionized ammonia in the downstream area was about 90 times less than the EPA's (1986) chronic exposure criteria.

The concentration of un-ionized ammonia within the center of the net-pens during the ebb tide was 23 times greater than the upstream, ambient concentration. However, this amounted to only about 10% of the chronic exposure criteria mentioned above. The within-pen results were from the widest set of net-pens (three pens abreast), under maximum loading, and minimal current conditions. Ammonia loading within other net-pen systems at Squaxin Island was probably less due to the two abreast configuration which allows greater dilution with surrounding waters.

Table 6. Results of experiment B from May 25, 1988. All data collected from 2 meters depth where the water temperature was 12.2 C *. pH remained at 8.0 throughout this sample collection.

Tidal Stage & station	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)	Dissolved Nitrogen** (Mean & SD) (mg/l)	Total Ammonia (mg/l)	Un-ionized Ammonia (mg/l)	Current Velocity (cm sec^{-1})
MID-FLOOD: 1200-1300 hours						
upstream:	11.7	132%	0.07 (0.020)	0.0155	0.00036	11.4
downs-stream	11.6	131%	0.15 (0.011)	0.0163	0.00037	5.2
EARLY EBB: 1500-1625 hours						
upstream:	12.2	137%	0.03 (0.006)	0.0069	0.00014	8.1
within pens***	10.4	117%	0.23 (0.006)	0.1606	0.00337	3.0
downstream	12.6	142%	0.03 (0.015)	0.0155	0.00033	7.9

* Total net-pen salmon biomasss was 118,600 kg for the flood and 97,970 kg for the ebb, due to differing sampling location. Ebb tide samples were collected downstream (south) of the larger WDF pens (number 2).

** Dissolved nitrogen values represent the total of nitrate, nitrite and ammonium. Nitrogen limitation for diatoms may occur below 0.04 mg/l.

*** within pens site was in center of the pen system (number 2, WDF) that were 3 cages wide by 11 cages long with 52,640 kg of fish.

Table 7. Ammonia concentrations at the Squaxin Island net-pens during the upstream/downstream analyses (experiment B). Distance to downstream sampling station was 30 m from facility number 3. Percent change in concentration is relative to ambient, upstream concentration. Chronic exposure concentration is the four day average recommended by EPA (1986).

Tidal Stage	Influencing Fish Biomass (Kg)	Total Ammonia Concentration (mg/l) with standard deviation in parenthesis		
		Upstream	Within Pens	Downstream
Flood tide	118,600 kg	0.0155 (0.00686)	----	0.0163 (0.00202)
percent increase of total ammonia -->				5.0%
percent increase of un-ionized ammonia -->				2.3%
percent of chronic toxicity concentration ->				1.2%
Ebb tide	97,970 kg	0.0069 (0.00038)	0.1606 (0.00337)	0.0155 (0.00262)
percent increase of total ammonia -->			2,337%	224%
percent increase of un-ionized ammonia -->			2.1%	2.1%
percent of chronic exposure concentration ->			11.2%	1.1%

Discussion

Experiment A: Effects on Phytoplankton

Phytoplankton abundance and the growth rate at the net-pens varied significantly with the stage of the tidal cycle or the time of day. The most striking feature of this analysis was the very similar pattern of primary productivity seen before and after fish were release from the pens (Fig. 5). There was a general trend toward increased phytoplankton density (chlorophyll a) and C-14 productivity at the net-pens during the morning ebb tide, with no significant difference during the afternoon flood tide, regardless of the sampling date and amount of fish held in the net-pens (compare figs. 5a and 5b).

Dissolved nitrogen to phosphorus ratios (table 4) indicated that growth was not limited due to nutrient depletion during the period before fish release, when greater phytoplankton density and significantly greater primary productivity was observed at the net-pens. Thus, the observed increased chlorophyll a during one tidal period of maximum fish biomass was not the result of nutrient production from the net-pens, but may be related to the natural hydrodynamics of Peale Passage.

The reference areas used in experiment A were selected to be within the same passage, but as remote as possible from the net-pens. These areas were near the source waters of Pickering and Dana Passages, which are both subject to fairly intense horizontal and vertical mixing (URS 1986b) compared to the shallow Peale Passage area. It is likely that vertical mixing, and accordingly, light limitation for phytoplankton cells in both of the source areas is much greater than in Peale Passage. By the time source waters bearing nutrients and phytoplankton seed stock reach the middle portions of Peale Passage, a day or longer has passed, allowing for significant growth to occur in the water column, which is entirely within the euphotic zone.

Although similar trends in C-14 primary productivity were similar on both sampling dates (figures 5a versus 5b), there was no statistical difference among sites on the later sampling date, and only on one tide of the earlier date. Further, the absolute values were different between sampling dates due to methodological differences and thus no comparison of primary production rates is possible between sampling dates.

Dissolved nutrient concentrations appeared to be roughly correlated with chlorophyll a values and were lower at all stations after most of the salmon were released. As discussed previously, Pease (1977) found an inverse relationship between the two throughout his study of Henderson Inlet. No causal relationship between these factors at the Squaxin Island net-pens is likely, due to the remoteness of the unperturbed reference areas, the relatively small amount of dissolved nitrogen contributed by the net-pens (theoretically about 33 kg/day total dissolved nitrogen) and results of nutrient sampling over the tidal cycle discussed below.

Most of the dissolved nitrogen concentrations at all stations during this study were greater than the threshold of limitation for diatom growth (0.04 mg/l; URS 1986). To show maximum effects, this study should have been conducted when surface waters were nearly depleted of dissolved nitrogen, if it ever occurs in the area, to test the possibility that the pens could cause or sustain a phytoplankton bloom. These results and pre-experiment nutrient sampling indicated that dissolved nitrogen values at the pens fluctuated regularly, above and below the 0.04 mg/l growth limitation threshold. This value obtained for nutrient limitation of diatoms is not absolute and should be used with caution because growth limitation also depends upon the concentration of phytoplankton cells and organic matter in the water, rates of remineralization of the organic matter to dissolved inorganic nitrogen (Harris 1986), and the type and size of phytoplankton (Redfield 1958, Ryther and Dunstad 1971, Eppley 1972, McCarthy 1980, URS 1986a).

On May 25, during the period of maximum fish biomass, increasing concentrations of dissolved nitrogen were seen at low tide on a south to north, long-channel axis (Fig. 3a). This observation suggests that nutrient-rich waters were entering from the north end of the passage at that time. Due to the location of the net-pens relative to the ebb tide flow (Fig. 2), it also suggests that nutrients from the net-pens were not the major source of the higher concentrations of dissolved nitrogen seen at the north end of the passage. Later that day during the flood tide, a similar concentration of dissolved nitrogen, about 0.07 mg/l (versus 0.09 mg/l), previously seen at the south end of the passage was observed immediately upstream of the net-pens in the results of the upstream/downstream analyses (experiment B). If time and budgets allowed, additional sampling between stations would have been useful to examine the trends more closely.

The elevated level of chlorophyll a at the net-pens prior to fish release and during the morning low tide (Fig. 4a; 24 ug/l), was nearly 4 times that of the reference stations. This non-replicated value was near the maximum values seen in two years of sampling in central Puget Sound (e.g., Anderson et al. 1984), but was much lower than summer values seen in nearby Henderson Inlet at control and experiment stations by Pease (1977). By high tide, the concentration of chlorophyll a had diminished at the Squaxin Island net-pen site.

After the fish release, there was significantly less chlorophyll a at the net pens on the morning low tide, but no difference by the afternoon. Compared to the period prior to fish release, and if one disregarded other data collected in this study, this suggests an effect due to the pens. However, the fact that dissolved nutrients were not limiting to phytoplankton growth prior to fish release is a more important factor and discounts any possible effect suggested by the increased chlorophyll a.

Another factor to be accounted for is the biomass of fish stock on hand before and after fish release. As previously mentioned, about 40% of the initial biomass (47,200 kg, both delayed release and fish for commercial purposes) was still on hand during the June 21 sampling date. However, this amount of biomass is small relative to the maximum amount of biomass that a typical two acre net-pen farm could maintain (up to 250,000 kg, J. Lindberg, pers. comm. in Weston 1986). I would have preferred that more of the fish had been released for the later sampling date, to provide a more representative experimental control, but that was not possible.

These results suggest that tidal stage, time of day and ambient nitrogen conditions were more important determinants of phytoplankton conditions at the net-pens and that nutrients from the net-pens did not produce a significant, measurable effect on the phytoplankton production. If time and materials allowed, several sampling stations midway between the pens and the reference areas would have been useful to search for a gradient of effects. Nevertheless, given the natural excess of total and dissolved nitrogen that existed throughout the study area at the time of the study, no effects from the pens were possible. Nitrogen may be limiting in the study area later in the summer, but most of the salmon have generally been released by that time.

Experiment B: Effects on Near Field Water Quality: Ammonia

This experiment involved measurement of nutrient levels upstream and downstream of the net-pen cages on May 25, when the maximum amount of salmon was present in pens. Divergent dissolved nitrogen results were seen between the two tidal stages monitored; the morning flood showed significantly elevated levels of dissolved nitrogen downstream, but only a very small, statistically insignificant increase in ammonia concentration. Monitoring during the afternoon ebb showed no significant difference in dissolved nitrogen concentration, but within that measure, the total ammonia concentration increased greatly as a percentage of upstream, ambient levels. However, the maximum concentration of un-ionized ammonia was only about 10 % of the EPA (1986) chronic exposure level for "salmonids and other sensitive coldwater species" and far below acute toxicity criteria.

The results of the flood tide analyses suggest that very rapid nitrification of ammonia occurred in the plume of the net-pen, consistent with general concepts of marine chemistry (Harris 1986). Most of the dissolved nitrogen was in the form of nitrate (NO_3 = 86% of dissolved N), not ammonia (NH_4^+ = 12% of dissolved N) a distance of 30 m downstream of the third net-pen system.

The concentration of dissolved nitrogen was the same at the upstream and downstream stations on the afternoon ebb (0.03 mg/l). Total ammonia was about 52% of the dissolved nitrogen in the downstream samples, compared with 70% inside the pens. In addition to nitrification, reduced ammonia downstream was apparently due to dilution during the ebb tide measurements.

The rate of ammonia nitrification can be approximated as follows, using the flood tide data. Assuming that 70% of the dissolved nitrogen within the pens was ammonia, as it was on the ebb, and given the average current velocity of 8.3 cm sec^{-1}, the mean distance from the center of all three net-pen systems to the downstream sampling location was 290 m. Accordingly, ammonia within the cages was converted from 70% to 12% of the total dissolved nitrogen concentration within about 1 hour. By then, the concentration of un-ionized ammonia was far below the exposure criteria for sensitive species such as salmonids (EPA 1986).

It has previously been conservatively assumed that all dissolved nitrogen produced by the net-pen fish was in the form of ammonia or urea, not nitrate (Weston 1986). While this is apparently true within the pens, the results presented here substantiate that nitrification converts the ammonia to nitrate over very short time periods, rapid compared to the doubling time of phytoplankton populations (minutes versus hours or days, respectively). The dominant dissolved nitrogen compound measured immediately downstream of the net-pens is nitrate. Nitrate is less preferred by phytoplankton cells, and its uptake rate is slower than that of ammonia.

The calculated production rate of dissolved nitrogen from the net-pen should be at least 0.22 to 0.28 g kg^{-1} fish day^{-1} greater than the ambient concentration. These values represent the sum of nitrate and ammonia produced by salmon (SAIC, 1986 and Weston 1986, respectively), multiplied by 0.87, the soluble fraction. Using the greater figure to be conservative, on the flood tide there should have been a net increase of 33.2 kg/day or 0.384 gram sec^{-1} nitrate and ammonia in the plume of the net-pen (118,600 kg x 0.28 g divided by 86,400 seconds per day). When spread over the average cross sectional area of all the pens (93.6 m long x 4 m deep = 374 m^2), and dispersed with the current (0.083 m sec^{-1}), this is equivalent to 0.012 mg/l greater than the upstream, ambient concentrations (37.9 kg divided by 31.04 m^3 sec^{-1}). The observed downstream concentration was 0.08 mg/l, about six times greater than ambient dissolved nitrogen, but less than an order of magnitude different. Variation among sample replicates was very little, lending credibility to the results. Using similar calculations for the ebb tide results, there should have been a similar predicted increase of dissolved nitrogen concentration downstream, but none was observed.

The lack of any measurable increase in dissolved nitrogen on one tidal phase and the increase on the other could be due to tidal hydrodynamics of the site and fish physiology. I have conducted similar studies at several other locations and have found increased concentrations of ammonia within or immediately downstream of the every net-pen system monitored (appendix B), but total nitrogen values have been more variable, sometimes even less than the upstream values.

Measured increase of nutrients that exceed predicted concentrations can be explained by several factors. The predicted increase was based on literature from freshwater hatcheries, not from marine net-pens. The Squaxin Island net-pen systems is mostly used for delayed release of relatively small (<40 g) coho salmon that require more rearing space per pound of fish than larger fish typically held in a commercial grow out facility. Accordingly, there is more netting and floats for growth of fouling organism, that may contribute nutrients. In addition, the net-pens are not removed and cleaned at the delayed release facility during the rearing period. The nets in a delayed release facility are installed in late winter and left in place until late spring to early summer. By the initial sampling time of this study (late spring), there was a considerable accumulation of invertebrate and algal fouling organisms on the nets. This condition is tolerated since the nets are removed in early summer for the remainder of the year. To determine the contribution of nutrients from floats and invertebrates growing on the nets, it would be useful to measure nitrogen concentrations at the Squaxin Island net-pens after the salmon were released, but before the nets are removed.

Finally, there is a inverse relationship between fish size and rate of metabolite production. Clark et al. (1985) found rapidly decreasing rate of ammonia production with increased fish size, about a 50% reduction from the 10 gram to 200 gram mean weight. The dominance of small fish at the Squaxin Island delayed release net-pens would therefore result in proportionately greater nitrogen discharge than a grow out facility with fish ranging in size from 20 grams to 10 kg or larger.

The lack of increased dissolved nitrogen downstream of the net-pens on the ebb tide could be due to dilution or unknown and irregular water motion. A one m deep drift stick placed immediately downstream of the net-pens moved very little for 20 minutes prior to the ebb tidal sample. From this observation, and numerous other observations by the author at some other facilities during low velocity periods of water movement, there appears to be an area immediately downstream of some net-pen facilities that may temporarily exhibit lack of water movement or anomalous patterns of water flow.

Other recent data collected to more accurately predict expected dissolved nitrogen concentrations downstream of net-pen facilities (appendix B) are insufficient in quantity at this time for regression analyses. The following narrative describes some of the recent studies.

Studies conducted near the world's largest net-pen facility, Domsea Farms, Inc., found no measurable effect on downstream water quality (D. Damkaer, NMFS, unpublished data cited in Weston 1986). Tidal flows in that area are greater than at the Squaxin Island net-pen site and annual production was approximately 8 times greater than at Squaxin Island.

Milner-Rensel Associates (1986) found similar results for ammonia production in a study of water quality near a relatively small net-pen system in Port Angeles Harbor (see appendix B). The pens contained 27,000 kg of fish and there was mean current velocity of 7 cm sec^{-1} during sampling. The concentration of ammonia increased within the net-pens, but immediately downstream the ammonia was converted to nitrate and diluted. The concentration of total ammonia inside the net-pens at Port Angeles was 0.020 mg/l, compared to 0.007 mg/l in the ambient, upstream water. The total ammonia concentration had diminished 30 m downstream of the net-pens to 0.011 mg/l, or 0.004 mg/l greater than the ambient, upstream value. Downstream nitrate increased 0.049 mg/l over ambient, although there was a fairly high variance within replicates. As the site was so near the Strait of Juan de Fuca, total dissolved nitrogen was much higher than at Squaxin Island and was 97% nitrate, the remainder being mostly ammonia.

Two years later in Port Angeles Harbor there were 192,000 kg of fish on hand with a current velocity of about 8 cm sec^{-1} (Rensel, unpublished data). In spite of the relatively large size and minimal currents during sampling, the concentration of toxic un-ionized ammonia was less than 6% of the EPA (1986) four day chronic exposure level for "salmonids and other sensitive coldwater species".

Another upstream/downstream analysis was conducted at a very small facility in the first year of operation at north Skagit Bay. The results indicate extremely minor increases of ammonia (0.001 mg/l increase in total ammonia downstream), and total dissolved nitrogen levels actually decreased downstream (Rensel 1988).

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Appendix A

Appendix Table A-1. Productivity data from Squaxin Island on May 25, 1988.

SAMPLE	Total Activity CPM	H#	DPM	
LA1	45322	126.3	48385	
LA2	40302	107.3	42667	
LA3	41287	105.7	43688	
LA4	41640	105.3	44056	
LA5	43032	105	45525	
LA6	37755	104.3	39934	
LA7	44236	105.3	46803	
LA8	41820	104.3	44234	
LA9	40342	104	42667	
LA10	34420	105	36414	
LA11	30763	105.7	32552	
LA12	29903	104.7	31632	
LB4	34385	105	36377	
LB5	45706	103.3	48331	
DA10	37593	104.7	39768	
LB10	42070	104.3	44499	
L-	40516	107	42890	
DA12	39540	103.7	41816	
mean & sd =			41791	4877

Sample	cpm	H#	dpm	mgC/m^3	mgC/m^3/h	site mean	st dev
N. Peale	11117	152.3	12098	35.09	6.19	7.37	2.36
1100 h	14557	141.7	15701	45.53	8.04		
	6355	144.3	6869	19.92	3.52		
	12779	144.7	13816	40.07	7.07		
	16809	149.3	18244	52.91	9.34		
	18191	143.7	19651	56.99	10.06		
NP dark	4681	144.3	5059	14.67	2.59	2.49	0.13
	4350	140.3	4687	13.59	2.40		
S. Peale	6411	146.3	6940	20.13	3.55	3.96	0.64
1100 h	8969	140.0	9661	28.02	4.94		
	5904	144.0	6379	18.50	3.26		
	6374	141.7	6875	19.94	3.52		
	7269	144.7	7858	22.79	4.02		
	8044	142.3	8680	25.17	4.44		
SP dark	5286	143.3	5709	16.56	2.92	2.77	0.21
	4740	143.7	5121	14.85	2.62		
Pens	24502	142.7	26448	76.70	13.54	14.10	3.40
1100 h	34093	143.3	36819	106.78	18.84		
	19775	143.0	21350	61.92	10.93		
	25980	155.3	28352	82.22	14.51		
	30384	146.7	32904	95.42	16.84		
	18019	144.3	19475	56.48	9.97		
Pens dark	6009	141.0	6478	18.79	3.32	2.74	0.82
	3918	139.7	4220	12.24	2.16		

Appendix Table A-1 Continued

Pens	7065	140.7	7615	22.08	8.28	7.33	0.83
1420 h	5805	141.3	6259	18.15	6.81		
	5461	144.3	5902	17.12	6.42		
	6984	138.7	7516	21.80	8.17		
	5574	146.7	6036	17.50	6.56		
	6585	143.0	7110	20.62	7.73		
Pens dark	5023	143.0	5423	15.73	5.90	5.98	0.11
	5151	144.7	5569	16.15	6.06		
N. Peale	8788	143.0	9488	27.52	10.32	9.83	2.35
1420 h	7746	141.3	8353	24.22	9.08		
	10884	142.7	11748	34.07	12.78		
	6095	142.7	6579	19.08	7.15		
NP dark	5074	142.7	5477	15.88	5.96	7.57	2.29
	7823	143.7	8451	24.51	9.19		
S. Peale	9809	142.7	10588	30.71	11.52	12.59	3.90
1420 h	10953	144.0	11835	34.32	12.87		
	15027	145.0	16250	47.13	17.67		
	7061	142.7	7622	22.10	8.29		
SP dark	8513	142.7	9189	26.65	9.99	10.63	0.90
	9567	147.3	10366	30.06	11.27		

Appendix Table A-2. Productivity data from Squaxin Island on June 21, 1988.

Total Activity				Time Zero			
SAMPLE	CPM	H#	DPM	SAMPLE	CPM	H#	DPM
LA1	30709	97.7	32431	LA1	12914	187.3	14640
LA2	32320	97.3	34130	LA2	17286	188.0	19615
LA3	40114	96.7	42355	LA3	23496	191.3	26792
DA2	31354	97.7	33112	DA2	15559	190.0	17707
LA4	42788	100.0	45209	LA4	14053	191.3	16025
LA5	33342	98.0	35213	LA5	15352	191.0	17497
LA6	32321	97.7	34134	LA6	19196	191.3	21888
DA4	57645	97.3	60872	DA4	15914	190.0	18111
LA7	35327	96.7	37300	LA7	23220	190.7	26454
LA8	41635	97.3	43966	LA8	18071	189.7	20558
LA9	56040	92.3	59131	LA9	20634	189.0	23449
DA6	46998	97.0	49626	DA6	28962	188.7	32899
LA10	34203	98.3	36125	LA10	13760	189.7	15653
LA11	32854	97.0	34691	LA11	17595	189.7	20015
LA12	30044	97.0	31725	LA12	20718	190.7	23604
DA8	36880	99.3	38961	DA8	16791	190.3	19118
LB1	33806	98.7	35709	LB1	15999	190.7	18227
LB2	44646	98.0	47152	LB2	23215	190.0	26420
LB3	55483	96.7	58582	LB3	31380	191.0	35766
DA10	35420	97.0	37401	DA10	38891	187.7	44114
LB4	31400	96.7	33154	LB4	45703	187.0	51788
LB5	41051	95.7	43337	LB5	26202	188.3	29746
LB6	38103	90.3	40196	LB6	35817	190.7	40805
DA12	47776	111.0	50643	DA12	20863	189.7	23733
mean & sd =			41465	mean & sd =			25193
			8848				9650

Inc Time 1 = 6.42
Inc Time 2 = 3.00

SAMPLE	CPM	H#	DPM	mg C/m^3	mg C/m^3/h	site means	st err
N. Peale	39926	190.7	45486	240.17	37.41	42.42	4.96
1020 h	35680	190.7	40649	182.93	28.49		
	40080	189.0	45547	240.91	37.52		
	42000	188.7	47709	266.48	41.51		
	43650	189.3	49626	289.18	45.04		
	52944	189.3	60193	414.24	64.52		
dark	24044	189.5	27344	25.46	3.97	-6.09	10.06
	14498	187.3	16435	-103.65	-16.14		
S. Peale	47033	189.0	53449	334.43	52.09	31.07	5.86
1020 h	44343	189.3	50414	298.51	46.50		
	31438	190.0	35778	125.29	19.51		
	33980	188.3	38576	158.40	24.67		
	31870	190.0	36271	131.11	20.42		
	33273	188.7	37795	149.15	23.23		
dark	31688	190.0	36063	128.65	20.04	10.94	9.10

Appendix Table A-2. Continued

	23020	189.7	26187	11.77	1.83		
Pens	30478	189.7	34671	112.18	17.47	67.39	16.82
1020 h	29487	189.3	33524	98.60	15.36		
	59108	190.0	67270	497.99	77.57		
	76650	187.3	86893	730.24	113.74		
	65200	189.0	74094	578.77	90.15		
	65085	189.7	74039	578.12	90.05		
dark	31450	189.3	35756	125.02	19.47	22.09	2.62
	33914	190.0	38597	158.65	24.71		
N. Peale	29780	190.7	33927	103.37	34.46	51.66	16.51
1330 h	43497	191.3	49598	288.85	96.28		
	44550	188.7	50605	300.77	100.26		
	35031	188.7	39793	172.80	57.60		
	22695	189.7	25817	7.39	2.46		
	26412	188.3	29985	56.71	18.90		
dark	25720	190.0	29271	48.27	16.09	0.40	15.69
	18724	190.3	21319	-45.84	-15.28		
S. Peale	25636	194.7	29384	49.60	16.53	65.47	18.93
1330 h	22595	188.3	25651	5.43	1.81		
	48384	191.7	55204	355.19	118.40		
	41857	189.7	47615	265.38	88.46		
	43607	188.7	49534	288.08	96.03		
	38120	189.3	43339	214.77	71.59		
dark	12257	190.0	13950	-133.07	-44.36	-22.69	21.67
	21942	189.0	24935	-3.05	-1.02		
Pens	25096	189.3	28532	39.52	13.17	31.80	12.34
1330 h	25007	189.0	28419	38.18	12.73		
	28747	190.0	32716	89.04	29.68		
	22293	187.7	25287	1.12	0.37		
	40063	189.0	45528	240.68	80.23		
	34303	190.0	39039	163.88	54.63		
dark	21967	190.3	25011	-2.15	-0.72	15.55	16.26
	29307	188.0	33256	95.44	31.81		

Appendix B

A number of studies have been conducted in Washington state to assess the nearfield effects of net-pen operation on nutrient and dissolved oxygen concentration in marine waters. Several of these studies have been conducted in accordance with methods outlined in the State of Washington's Recommended Interim Guidelines for the Management of Salmon Net-pen Culture in Puget Sound (SAIC 1986). Other studies, conducted prior to the guidelines, were essentially the same, although within net-pens sampling stations were utilized instead of the the first downstream sampling station.

All of the near field studies (Appendix Table B-1) have shown increased concentrations of ammonia immediately downstream or within the net-pens. Total ammonia values have increased from 3 to 2,327%. However, the amount of un-ionized ammonia increased only a few percent of the four-day maximum chronic exposure level recommended by EPA (1986), ranging from 0.9 to 11.2%. The maximum increase (11.2% of the recommended chronic exposure value) was found within, not downstream, of the largest of three net-pen systems at Squaxin Island. These pens were configured to have three pens wide by 10 pens long, causing significantly reduced water flow within the center pens, where samples were collected. As the concentration of any waste nutrient is greatly dependent on tidal flow rate, and the samples were collected in a worst case area at only a few cm per second flow, this appears to be a worst-available-case analysis. To compensate for reduced flows and possible reduced growth, fish culturists at that site have reduced fish loading within the center pens.

Studies of nutrients in "upstream" and "downstream" waters immediately adjacent to net-pens in Washington state have also indicated that relatively rapid rates of nitrification occur, i.e., ammonia (NH_4^+) is oxidized by microbial action to nitrate (NO_3). A typical scenario involves elevated concentrations of ammonia within the net-pens but a short distance downstream, the ammonia has been converted to nitrate.

The data has been included here to illustrate the amount of ammonia produced by a wide variety of pens, of differing size. The results show that adverse effects are minimal, even at relatively large facilities. The continued collection of this data will eventually allow more precise calculation of the total dissolved nitrogen produced from marine net-pen reared salmon, the fouling organisms on the nets and floats and the fish associated with the net-pen facility. Such data will allow more precise calibration of numerical models that are designed to assess the possible cummulative effect of salmon net-pens in restricted embayments. Presently the only data available for this purpose is from freshwater hatchery culture of relatively small fish.

Appendix Table B-1. Summary of dissolved nitrogen, total and un-ionized ammonia production from marine net-pen farms in Washington state compared to maximum recommended four day exposure concentration (EPA 1986). Percent change in concentration is relative to upstream concentration.

Site - Data Source & Instantaneous loading (Kg)	Concentration (mg/l) & Percent Change: Upstream	Within Pens	30 meters Downstream
PORT ANGELES HARBOR 1/ 27,000 kg			
Total dissolved nitrogen-->	0.832	0.882	0.887
Total Ammonia -->	0.0074	0.0201	0.0119
NH_4^+ percent increase relative to ambient ->		272%	62%
percent of ammonia that is toxic (NH_3) -->		1.8%	1.8%
percent of chronic toxicity concentration ->		1.5%	0.9%

	Upstream	6 meters Downstream	30 meters Downstream
SKAGIT BAY 2/ (Lone Tree Pt.) 4,300 kg			
Total dissolved nitrogen-->	1.067	1.131	1.139
Total Ammonia -->	0.0277	0.0303	0.0287
NH_4^+ percent increase relative to ambient ->		9%	3%
percent of ammonia that is toxic (NH_3) -->		0.3%	0.3%
percent of chronic toxicity concentration ->		1.9%	1.8%

SQUAXIN ISLAND 3/ (Peale Passage) 118,600 kg

	Upstream	6 meters Downstream	30 meters Downstream
Total dissolved nitrogen-->	0.07	----	0.15
Total Ammonia -->	0.0155	----	0.0163
NH_4^+ percent increase relative to ambient ->			5%
percent of ammonia that is toxic (NH_3) -->			2.3%
percent of chronic toxicity concentration ->			1.2%

Appendix Table B-1, continued

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SQUAXIN ISLAND 4/ (Peale Passage) 97,970 kg

	Concentration (mg/l) & Percent Change		
	Upstream	Within pens	30 meters Downstream
Total dissolved nitrogen-->	0.03	0.23	0.03
Total Ammonia -->	0.0069	0.1606	0.0155
NH_4^+ percent increase relative to ambient ->		2,327%	225%
percent of ammonia that is toxic NH_3 -->		2.1%	2.1%
percent of chronic toxicity concentration ->		11.2%	1.1%

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PORT ANGELES HARBOR 5/ 192,500 kg

	Upstream	6 meters Downstream	30 meters Downstream
Total dissolved nitrogen-->	1.4869	1.6688	1.6207
Total Ammonia -->	0.0343	0.0873	0.0516
NH_4^+ percent increase relative to ambient ->		254%	150%
percent of ammonia that is toxic (NH_3) -->		1.5%	1.5%
percent of chronic toxicity concentration ->		6.4%	3.8%

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PORT ANGELES HARBOR 6/ 192,500 kg

	Upstream	6 meters Downstream	30 meters Downstream
Total dissolved nitrogen-->	1.5862	1.5771	1.4992
Total Ammonia -->	0.0122	0.0642	0.0336
NH_4^+ percent increase relative to ambient ->		526%	275%
percent of ammonia that is toxic (NH_3) -->		1.5%	1.5%
percent of chronic toxicity concentration ->		4.7%	2.4%

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Data sources and downstream velocity: 1) Milner-Rensel Associates 1986, 8.0 cm sec^{-1} @ 30m downstream; 2) Rensel 1988, 38.8 cm sec^{-1} @ 6m; 3) See main text, flood tide, 5.2 cm sec^{-1}; 4) See main text, ebb tide, 7.9 cm sec^{-1}. 5) Rensel unpublished on flood tide, 8.2 cm sec^{-1}; 6) Rensel unpubished on ebb tide, 8.4 cm sec^{-1}.

APPENDIX D

INFECTIOUS DISEASES OF SALMON IN THE PACIFIC NORTHWEST

FISH DISEASES

Metazoan Parasites. External copepods (Lepeophtheirus salmonis and Caligus sp.) and monogenean gill flukes Laminiscus sterkowli are the only metazoan parasites that have been observed in sufficient intensities to be considered significant pathogens of net-pen reared fish in Washington (Kent and Elston, 1987b; L. W. Harrell, NMFS, Manchester, WA, pers. comm).

Protozoans. Diseases due to marine protozoan parasites are common in net-pen reared salmon. These include Parvicapsula sp. (Myxosporea: Myxozoa) which causes kidney disease in pen-reared coho salmon (Hoffman 1984; Johnstone 1984, Kent and Elston 1987b) for which cod is the likely reservoir for infection (Johnstone, 1984); Paramoeba pemaquidensis, a ubiquitous, normally free-living amoeba which infects gills (Kent et al. 1988b); an unidentified protozoan (rosette agent) which infects inflammatory cells of maturing chinook salmon in net-pens (Elston et al. 1986; Harrell et al. 1986); and a microsporidan protozoan which infects blood-forming cells of chinook and causes severe anemia (Elston et al. 1987).

Freshwater protozoan pathogens may also be transmitted with fish when they are introduced to net-pens. Kent and Elston (1987b) observed infections by a microsporidan similar to Loma salmonae (Microspora) in the gills of coho salmon held in net-pens. These infections were apparently contracted in freshwater. Ichtyobodo (Costia) is a common flagellate protozoan pathogen in freshwater which can apparently survive and cause disease in fish after seawater transfer (Ellis and Wooten 1978) and it has occasionally been associated with gill disease in pen-reared salmon in Washington.

Bacteria. Renibacterium salmoninarum, the causative agent of bacterial kidney disease of salmonids, is widespread in net-pen reared salmon in Washington State, as well as British Columbia, and is a serious threat to the industry (Evelyn 1988). Salmonid fishes are the primary hosts for this obligate pathogen but herring (Clupea harengus) and black cod (Anoploma fimbria) can be infected experimentally by injection of the bacterium (**Traxler and Bell in press**). It is believed that the organism is not part of the normal bacterial aquatic microflora (Austin and Austin 1987) and salmon are the likely reservoir for infection (Fryer and Sanders 1981). The disease can be transmitted either horizontally (from fish to fish) or vertically within eggs (Evelyn et al. 1984), and it is often exacerbated after infected fish are transferred to seawater (Banner et al. 1983). The bacterium can be detected in pen-reared salmon several months after transfer to seawater and the disease can be transmitted to other salmon in adjacent net-pens (Evelyn 1988). The bacteria persist in wild fish in seawater (Banner et al. 1986) and it is probable that wild brood stocks are a source of infections in some fish farms (Evelyn 1988).

It is difficult to treat fish with clinical disease so prevention is the most common control method. Prevention strategies include screening brood stock and discarding eggs from positive females and screening smolts prior to seawater introduction. Erythromycin injection of females prior to spawning appears to induce high enough levels of the antibiotic in eggs to reduce vertical transmission to the fry (Evelyn et al. 1986) and this practice has been initiated at several fish farms.

Furunculosis, caused by the Gram-negative bacterium *Aeromonas salmonicida*, often causes severe disease in freshwater fishes. Although the bacterium often originates in freshwater, it can apparently survive and spread in seawater (Scott 1968), and it has been recognized as a pathogen in seawater in Washington (Novotny 1978). As with *Renibacterium*, epizootic disease in salmon with latent infections occurs after transfer to seawater (Cox et al. 1986; Smith et al. 1982). Though the disease is most often observed in salmonid fishes, it has also been reported in several non-salmonid marine and freshwater species (Elliot and Shotts 1980; McCarthy 1975; Morrison et al. 1984). Furunculosis is usually treated with oxytetracycline or Romet 30. There is active research on an effective bath immersion vaccine, but this is not routinely used in production facilities.

Vibriosis, caused by marine bacteria of the genus *Vibrio*, is a cosmopolitan disease infecting many fish species. It frequently occurs in net-pen reared fish in Washington State (Novotny 1978) and British Columbia (Evelyn 1971). Though several *Vibrio* spp. have been incriminated as agents of disease in cultured fishes, only three species are well documented pathogens of salmonid fishes; *V. anguillarum*, *V. ordalii* and *V. salmonicida* (Egidius 1987). Only the former two species have been reported in fish from Washington (Novotny 1978). *Vibrio anguillarum* is ubiquitous in the marine environment (Muroga et al. 1986) and can survive without a fish host for several months (Toranzo et al. 1982). Therefore, *V. anguillarum* is considered a facultative pathogen and does not require a fish host to survive in the marine environment (Muroga et al. 1986). Whereas *V. anguillarum* infects over 40 fish species and has been isolated from wild as well as cultured fishes, *V. ordalii* has only been isolated from pen-reared salmon.

A newly identified *Vibrio* sp., *V. salmonicida* is the causative agent of Hitra disease in net-pen reared Atlantic salmon in Europe (Egidius et al. 1986; Wiik and Egidius 1986). *Vibrio salmonicida* has not been detected in salmon reared in North America. No *Vibrio* spp. pathogenic to man have been associated with disease in salmon and human health concerns with *Vibrio* spp. have been restricted to warm water aquaculture (Egidius 1987). Unlike *R. salmoninarum*, *Vibrio* infections usually occur only after seawater transfer. Vibriosis is usually an acute systemic disease and fish which recover show strong immunological protection against reinfection. Effective vaccines are commercially available which protect fish from *V. anguillarum* and *V. ordalii* infections and the disease is prevented by vaccinating fish prior to seawater introduction.

Viruses. Though several viral diseases are important in salmon during their freshwater phase of development, none have been reported from salmon in seawater. Infectious hematopoietic necrosis (IHN) is of most concern in the Pacific Northwest. This virus is a persistent problem in fry and fingerling chinook salmon at several hatcheries. Apparently only fingerlings and returning salmon in freshwater are infected with IHN and it has not been isolated from fish in seawater. *In vitro* studies by Pietsch et al. (1977) and Toranzo et al. (1982) indicate that the virus survives poorly in seawater.

Idiopathic Diseases. Kent and Elston (1987a) observed a condition similar to pancreas disease in Atlantic salmon reared in Washington. This disease has previously been described in Atlantic salmon reared in Europe during their first year in seawater (Munro et al. 1984; McVicar 1987). Fish become emaciated and histological examination reveals diffuse necrosis and atrophy of the exocrine pancreas. The cause is unknown. Researchers in Scotland have proposed various etiologies; Ferguson et al. (1986) suggested that the condition may be related to vitamin E and selenium deficiencies, whereas Munro et al. (1984) reported epizootiological evidence consistent with an infectious etiology. If the cause of this disease is an infectious agent, it is of marine origin with no link to freshwater or stock origin (McVicar 1987). An infectious etiology is also indicated in a study by Ferguson (1986). Fish from the same egg lot were transferred to two sites. Fish at the site where the disease was enzootic developed the disease while fish transferred to a site with no history of the disease remained unaffected.

APPENDIX E

THE ECONOMICS OF SALMON FARMING

THE ECONOMICS OF SALMON FARMING:

ROBERT L. STOKES

REPORT TO THE WASHINGTON STATE
DEPARTMENT OF FISHERIES

OCTOBER 1988

EXECUTIVE SUMMARY

This report examines three economic issues arising from recent growth in Washington's salmon farming industry. The first issue is potential gains in output, income and employment to the economies of the state and of selected counties. The second is impact on revenues and expenditures of state government. The third is implications for real estate values of various (externally provided) assumptions concerning visual impacts of salmon farming facilities. The report concludes with a benefit-cost analysis of hypothetical siting decisions.

The report examined neither the universe of policy issues elsewhere addressed in the EIS, nor the subset of those issues amenable to economic analysis or comment. Hence, the reader is referred other sections of the EIS for discussion of the effects of environmental wasteloadings and fish disease; consequences for sport fishing, and marine recreation; and economic effects of public perception concerning environmental quality. An article by James A. Crutchfield (Appendix L) also provides a useful overview of the entire salmon farming issue from an economic as well as policy perspective.

Washington's salmon farming industry is a segment of the world's rapidly growing mariculture industry. After some years of concentration on Pacific salmon (pan size coho), industry interest has shifted to production of mature Atlantic salmon. Several sites have been established in the past two years and many more are in various stages of planning or application for permits.

The combination of favorable water temperatures, sheltered waters and infrastructure make Washington's Puget Sound one of the prime sites in the U.S. for salmon farming. Current operators compete favorably with Norwegian and Scottish producers for U.S. markets, and industry leaders feel that the combination of domestic and Japanese demand provides a market base for extensive future growth. The following are this authors general conclusions concerning the economic consequences for Washington state (and selected counties) of permitting or encouraging expansion of the fish farming industry:

- The economic impacts of such growth were determined by assuming that a representative Atlantic salmon facility (1,000,000 lbs production, $5,000,000 revenue) was sited in each of Clallam, Jefferson, Kitsap, San Juan, and Skagit Counties. Conclusions of that analysis were that the state economy would gain (from all 5 sites) $38-$48 million in output, $11-$21 million in household income and 257-303 jobs. Average County impacts for a single site were output $5.8-$6.8 million, household income $1.1-$2.1 million and 40-51 jobs.

- These economic impact results provided the basis for estimates of state fiscal (revenue and expenditure) consequences. Depending on the economic impact values used and method of relating economic impacts to fiscal consequences, salmon farming would contribute $.36-$2.26 million to state revenues and $1.08-$1.48 to state expenditures.

- Property values were examined by collecting and statistically analyzing 335 current real estate listings and assessed property valuations. The average front footage price of $409 had a standard deviation of $290, approximately half of which could be accounted for by general location (County), land type (high/low bank), and improvements (water, sewer, etc.). The remaining or "residual" price variation was presumed to result, at least in part, from variations in visual aesthetic quality.

- Finally, benefit-cost and sensitivity analyses were used to relate gross economic gains (household income) to potential losses (adverse property consequences). Sixty-four benefit-cost ratios were calculated to reflect all combinations to data input ranges and necessary subjective judgments, the latter including opportunity costs of labor, interest rates, degree and geographic extent of adverse visual impact, and interest rates. All ratios (including those most unfavorable to the fish farming industry) exceed unity, suggesting net statewide economic gains from salmon farming. Average results for all sensitivity calculations and results calculated under assumptions favorable to the industry indicated substantial net economic gains.

These results should, of course, be interpreted in terms of the limited scope of the study. They suggest favorable balances between the benefits and costs calculated in the course of accomplishing the three study tasks; regional input-output analysis, state fiscal analysis, and property value analysis. Also, as noted, each result depends on assumed rather than estimated adverse visual effects on property. Overall assessment of the economic consequences of salmon farming for Washington must also include consideration of numerous other economic issues, including, in particular, the economic implications of issues addressed from an environmental or policy perspective in the main body of this EIS.

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INTRODUCTION

This report, prepared under contract with the Washington State Department of Fisheries, examines selected economic aspects of the Washington salmon farming industry. The stimulus for this study is a general review of siting policy currently being conducted by the Washington Department of Fisheries and other state agencies.

Several of the issues referred to in recent salmon farm siting decisions have been economic in nature. These include potential gains in state and county income and employment, fiscal impacts on state and local governments, and adverse consequences for waterfront land values in the vicinity of proposed sites.

Each of these issues is addressed below. A brief history and description of the salmon farming industry is provided in Section I, followed by a discussion of regional input-output theory (Section II) and discussion of the economic data used to characterize salmon farming in input-output terms (Section III). Section IV reports input-output results (state/county employment, income, etc.) which are applied to the calculation of state fiscal impacts in Section V. Section VI deals property values and Section VII assembles the preceding economic data into a benefit-cost model. sensitivity analysis.

I. THE SALMON FARMING INDUSTRY

Salmon farming is emerging in Washington State as part of a rapidly growing world mariculture industry. Mariculture is the cultivation of marine organisms for harvest, as distinguished from capture fisheries, the harvest of naturally occurring fish, and aquaculture (the cultivation of freshwater organisms). Historically, mariculture has been a major world producer of shellfish and finfish. Washington State has long participated in mariculture as one of the primary US oyster producers.

Much of the science and technology which now underpins private salmon mariculture was initially developed to support Pacific Northwest public hatchery programs. In the past several decades research supporting those hatchery programs has focused on all five species of Pacific salmon, as well as on Atlantic salmon. Early research on the hatchery production of Atlantic salmon was done at the University of Washington US and Norwegian biologists working in cooperation.

Transfer of Pacific salmon production technology to the private sector was initiated by, among others, the Weyerhauser

Corporation in Oregon and Domsea Farms (Cambell Soup Co.) in Washington. The first private production of Atlantic salmon began in Norway in 1971, leading to a booming Atlantic salmon farming industry in that nation, and later in Scotland as well.

In the Pacific Northwest, British Columbia has seen the greatest growth in salmon farming. The first major British Colombia site was licensed in 1973, with major production beginning in about 1985. Today (1988) 128 sites produce 900 metric tons of chinook, coho, and Atlantic salmon, as well as rainbow trout and arctic char.[1]

After many years of relatively stable production (1.5 to 2.0 million lbs from 1979 to 1986) Washington State has become the scene of increasing interest in Atlantic salmon pen culture. There are now 15 sites operating in Puget Sound and North Puget Sound Counties, as well as 17 in the permit cycle. Total 1987 production of 3.4 million pounds consisted primarily of coho, but included 400 thousand pounds of Atlantic salmon.[2]

Puget Sound is the largest potential salmon farming site in the United States because of its desirable water temperature, sheltered waters, and good economic infrastructure. Salmon farms currently in production compete successfully with Norwegian and Scottish imports on the US West Coast and in the Midwest. Industry spokesmen suggest that production could expand significanlty without saturating potential markets, particularly if, for Japanese markets, Washington's geographic advantage over Europe can be exploited.

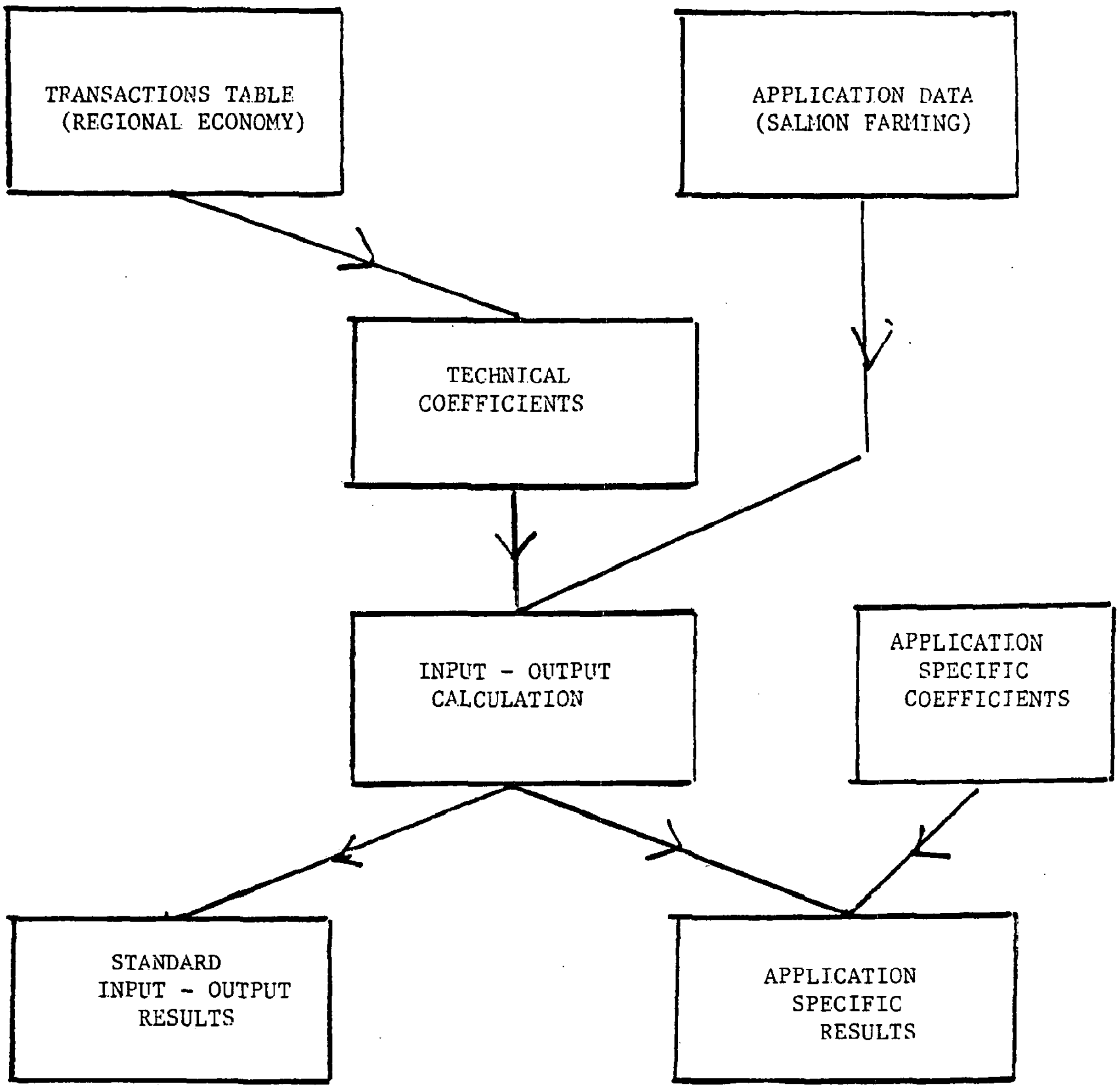
II. INPUT - OUTPUT THEORY

Input-output theory is a widely used method of regional economic analysis, appropriate to the issues addressed in this report. Developed as a post World War II extension of Keynsian national income analysis, input-output theory shares the Keynsian assumption of an economy with slack producing capacity. In such an economy output is, over moderate variations, determined by aggregate demand. This characterization fits the situation of "open" regional economies, such as states and counties. In such open economies, labor and other inputs are available at relatively constant prices, and are employed in relatively fixed proportions to produce goods and services demanded by regional and external consumers (Richardson, 1972).

Typical evaluation applications of input-output theory include determinations of the regional output, income and employment implications of specific industrial facilities siting decisions. Planning applications have included studies anticipating the public infrastructure requirements of economic growth, and more recently, studies assessing regional energy requirements and environmental waste loads.

The general procedures by which input-output analysis extracts estimates of regional output, income and employment from externally provided estimates of final demand are traced in figure 2.1. Economic information on the entire regional economy

Figure 2.1 Schematic Representation of Input - Output Analysis



(usually obtained from background studies) is recorded in a transactions table, from which a table a technical coefficients is computed. Data on the industry or facility under analysis is then collected (as part of the specific application) and introduced as a column vector of final demands. These final demands are aggregated into the same catagories as those used in the transactions table. Matrix multiplication of the final demand vector and the technical coefficients table (and side calculations as necessary), produce the desired results.

These procedures conform to specific accounting principles and technological assumptions, which are illustrated with the Clallam County input-output model. That model and structurally identical ones for Washington State; and for Jefferson, Kitsap, San Juan and Skagit Counties were developed for this study from data found in the US Forest Service IMPLAN system. These models necessarily reflect 1982 economic conditions. This is because 1982 is the effective year of IMPLAN, and is also the effective year of the most recent complete census of manufactures. The reader interested in the detailed mechanics of the input-output procedures employed here is invited to trace the calculations reported in tables 2.1 to 2.4 (U.S. Forest Service, 1988).

For the more general reader, we offer the following observations on the appropriatness of input-ouput analysis to the task a hand. An assumption crucial to the application of input-output analysis is that the inputs and outputs of regional industries can be varied in constant proportions, without altering prices, encountering physical resource constraints, or

Table 2.1 Clallam County Transaction Table
(thousand dollars)

1 Agriculture, Fisheries, Fisheries
2 Mining
3 Construction
4 Manufacturing
5 Transport, Comm, Public Utilities
6 Wholesale Trade
7 Retail Trade
8 Finance, Insurance, Real Estate
9 Services
10 Federal Government
11 State and Local Government

VA Value Added
IMP Imports
PCE Personal Consumption
FD Final Demand
T Total

	1	2	3	4	5	6	7	8	9	10	11	PCE	FD	T
1	461	0	61	776	1	1	1	239	349	1	2	795	5974	8660
2	0	0	4	7	0	0	0	0	0	0	0	0	52	62
3	88	0	64	4403	1619	8	441	4604	1663	1	1782	0	29650	44322
4	56	0	2003	57097	212	15	1478	396	1692	2	44	1639	311085	375719
5	224	2	993	8511	7988	48	1789	586	3996	9	480	8132	24614	57371
6	1	0	9	49	3	0	1	0	15	0	0	35	1067	1181
7	23	0	1830	641	145	2	73	113	291	1	21	21423	34803	59365
8	187	1	216	1340	555	18	1501	3554	2945	3	31	35603	58217	104172
9	114	2	1431	5690	1720	77	1763	1512	6276	27	115	37753	82031	138511
10	0	0	6	13	17	0	3	190	11	12	1	145	357	756
11	11	0	27	1012	255	2	110	131	341	1	48	1589	64494	68022
VA	3250	34	16646	122780	24727	786	43037	81322	73261	458	63892	0	7917	438110
IMP	4245	22	21033	173399	20130	224	9169	11525	47672	241	1608	330995	0	620261
T	8660	62	44322	375719	57371	1181	59365	104172	138511	756	68022	438110	620261	1916511

Table 2.2 Clallam County Technical Coefficients
(thousand dollars)

1 Agriculture, Fisheries, Fisheries
2 Mining
3 Construction
4 Manufacturing
5 Transport, Comm, Public Utilities
6 Wholesale Trade
7 Retail Trade
8 Finance, Insurance, Real Estate
9 Services
10 Federal Government
11 State and Local Government

VA Value Added
PCE Personal Cons
T Total

	1	2	3	4	5	6	7	8	9	10	11	PCE
1	0.0532	0.0000	0.0014	0.0021	.0000	0.0009	.0000	0.0023	0.0025	0.0019	.0000	0.0018
2	0.0000	0.0021	0.0001	.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0102	0.0076	0.0014	0.0117	0.0262	0.0071	0.0074	0.0442	0.0120	0.0012	0.0262	0.0000
4	0.0065	0.0042	0.0452	0.1520	0.0037	0.0131	0.0249	0.0038	0.0122	0.0027	0.0006	0.0037
5	0.0258	0.0322	0.0224	0.0227	0.1392	0.0404	0.0301	0.0056	0.0288	0.0116	0.0070	0.0186
6	0.0001	0.0000	0.0002	0.0001	0.0001	0.0001	.0000	.0000	0.0001	0.0001	.0000	0.0001
7	0.0026	0.0003	0.0413	0.0017	0.0025	0.0015	0.0012	0.0011	0.0021	0.0015	0.0003	0.0489
8	0.0216	0.0180	0.0049	0.0036	0.0097	0.0148	0.0253	0.0341	0.0213	0.0045	0.0005	0.0813
9	0.0132	0.0319	0.0323	0.0151	0.0300	0.0652	0.0297	0.0145	0.0453	0.0355	0.0017	0.0862
10	.0000	0.0000	0.0001	.0000	0.0003	0.0002	0.0001	0.0018	0.0001	0.0161	.0000	0.0003
11	0.0013	0.0021	0.0006	0.0027	0.0044	0.0016	0.0018	0.0013	0.0025	0.0010	0.0007	0.0036
VA	0.3753	0.5511	0.3756	0.3268	0.4310	0.6659	0.7250	0.7807	0.5289	0.6058	0.9393	0.0000
T	0.5099	0.6494	0.5255	0.5385	0.6491	0.8108	0.8455	0.8894	0.6558	0.6818	0.9764	0.2445

Table 2.3 Clallam County Economic Impact Illustration
(thousand dollars)

1 Agriculture, Fisheries, Fisheries
2 Mining
3 Construction
4 Manufacturing
5 Transport, Comm, Public Utilities
6 Wholesale Trade
7 Retail Trade
8 Finance, Insurance, Real Estate
9 Services
10 Federal Government
11 State and Local Government
VA Value Added
T Total

ROUND	SECTOR												
	1	2	3	4	5	6	7	8	9	10	11	VA	T
1	$20.16	$.00	$14.53	$49.31	$86.17	$0.25	$92.58	$162.77	$180.33	$0.72	$9.19	$368.15	$984.15
2	$2.69	$.00	$13.52	$15.11	$29.79	$0.07	$19.63	$43.17	$49.13	$0.48	$2.71	$365.07	$541.38
3	$1.08	$.00	$3.78	$5.66	$13.92	$0.04	$18.69	$33.15	$36.51	$0.22	$1.72	$100.67	$215.46
4	$0.43	$.00	$2.56	$2.50	$5.87	$0.01	$5.26	$10.76	$12.02	$0.11	$0.61	$70.20	$110.34
5	$0.21	$.00	$0.88	$1.10	$2.82	$0.01	$3.60	$6.55	$7.21	$0.05	$0.34	$23.69	$46.47
6	$0.09	$.00	$0.51	$0.51	$1.24	$.00	$1.23	$2.43	$2.71	$0.02	$0.14	$13.88	$22.76
7	$0.04	$.00	$0.20	$0.23	$0.59	$.00	$0.71	$1.32	$1.45	$0.01	$0.07	$5.29	$9.92
8	$0.02	$.00	$0.10	$0.11	$0.26	$.00	$0.27	$0.53	$0.59	$.00	$0.03	$2.81	$4.73
9	$0.01	$.00	$0.04	$0.05	$0.12	$.00	$0.14	$0.27	$0.30	$.00	$0.01	$1.15	$2.10
10	$.00	$.00	$0.02	$0.02	$0.06	$.00	$0.06	$0.11	$0.13	$.00	$0.01	$0.58	$0.99
T	$24.75	$0.01	$36.14	$74.60	$140.82	$0.39	$142.19	$261.08	$290.38	$1.62	$14.84	$951.49	$1,938.30

Table 2.4 Clallam County Economic Impact Illustration
First Round Calculation

Sector		1	2	3	4	5	6
First Round Input >	>	300	0	0	250	250	0
	1	300 X 0.0532 +	0 X 0.0000 +	0 X 0.0014 +	250 X 0.0021 +	250 X 0.0000 +	0 X 0.0009
	2	300 X 0.0000 +	0 X 0.0021 +	0 X 0.0001 +	250 X 0.0000 +	250 X 0.0000 +	0 X 0.0000
	3	300 X 0.0102 +	0 X 0.0076 +	0 X 0.0014 +	250 X 0.0117 +	250 X 0.0282 +	0 X 0.0071
	4	300 X 0.0065 +	0 X 0.0042 +	0 X 0.0452 +	250 X 0.1520 +	250 X 0.0037 +	0 X 0.0131
	5	300 X 0.0258 +	0 X 0.0322 +	0 X 0.0224 +	250 X 0.0227 +	250 X 0.1392 +	0 X 0.0404
	6	300 X 0.0001 +	0 X 0.0000 +	0 X 0.0002 +	250 X 0.0001 +	250 X 0.0001 +	0 X 0.0001
	7	300 X 0.0026 +	0 X 0.0003 +	0 X 0.0413 +	250 X 0.0017 +	250 X 0.0025 +	0 X 0.0015
	8	300 X 0.0216 +	0 X 0.0180 +	0 X 0.0049 +	250 X 0.0036 +	250 X 0.0097 +	0 X 0.0148
	9	300 X 0.0132 +	0 X 0.0319 +	0 X 0.0323 +	250 X 0.0151 +	250 X 0.0300 +	0 X 0.0652
	10	300 X 0.0000 +	0 X 0.0000 +	0 X 0.0001 +	250 X 0.0000 +	250 X 0.0003 +	0 X 0.0002
	11	300 X 0.0013 +	0 X 0.0021 +	0 X 0.0006 +	250 X 0.0027 +	250 X 0.0044 +	0 X 0.0016
	VA	300 X 0.3753 +	0 X 0.5511 +	0 X 0.3756 +	250 X 0.3268 +	250 X 0.4310 +	0 X 0.6659

Sector		7	8	9	10	11	PCE	First Round Ou Second Round I
First Round Input >	>	0	0	125	0	0	1850.	
	1: +	0 X 0.0000 +	0 X 0.0023 +	125X 0.0025 +	0 X 0.0019 +	0 X 0.0000 +	185X 0.0018 =	20.16
	2: +	0 X 0.0000 +	0 X 0.0000 +	125X 0.0000 +	0 X 0.0000 +	0 X 0.0000 +	185X 0.0000 =	.00
	3: +	0 X 0.0074 +	0 X 0.0442 +	125X 0.0120 +	0 X 0.0012 +	0 X 0.0262 +	185X 0.0000 =	14.53
	4: +	0 X 0.0249 +	0 X 0.0038 +	125X 0.0122 +	0 X 0.0027 +	0 X 0.0006 +	185X 0.0037 =	49.31
	5: +	0 X 0.0301 +	0 X 0.0056 +	125X 0.0288 +	0 X 0.0116 +	0 X 0.0070 +	185X 0.0186 =	86.17
	6: +	0 X 0.0000 +	0 X 0.0000 +	125X 0.0001 +	0 X 0.0001 +	0 X 0.0000 +	185X 0.0001 =	0.25
	7: +	0 X 0.0012 +	0 X 0.0011 +	125X 0.0021 +	0 X 0.0015 +	0 X 0.0003 +	185X 0.0489 =	92.58
	8: +	0 X 0.0253 +	0 X 0.0341 +	125X 0.0213 +	0 X 0.0045 +	0 X 0.0005 +	185X 0.0813 =	162.77
	9: +	0 X 0.0297 +	0 X 0.0145 +	125X 0.0453 +	0 X 0.0355 +	0 X 0.0017 +	185X 0.0862 =	180.33
	10: +	0 X 0.0001 +	0 X 0.0018 +	125X 0.0001 +	0 X 0.0161 +	0 X 0.0000 +	185X 0.0003 =	0.72
	11: +	0 X 0.0018 +	0 X 0.0013 +	125X 0.0025 +	0 X 0.0010 +	0 X 0.0007 +	185X 0.0036 =	9.19
	VA: +	0 X 0.7250 +	0 X 0.7807 +	125X 0.5289 +	0 X 0.6058 +	0 X 0.9393 +	185X 0.0000 =	368.15

otherwise changing base period economic and technological conditions. These conditions are reasonably well satisfied in this application. This because the current and proposed salmon farming industry is small in relation to the economies of Washington State and its coastal counties. One exception to this expectation of constant technical coefficients is the possibility that a growing salmon farming industry might lead to import substitution. That is, instate suppliers may avail themselves of opportunities to provide specialized inputs that are now imported. This possibility is addressed by means of sensitivity analysis (maximum and minimum impact calculations) described in sections III and IV.

Another important assumption is that the accounting stance of relevant decisionmakers coincides with the scope of the input-output model. Such a coincidence would seem to exist for this evaluation of state and county siting policy. Even within a regional accounting stance, though, input-output results cannot, without modification, be interpreted as net benefits in the benefit-cost sense. This qualification is addressed in section VII, where input-output results are given a net benefits interpretation, but only after subtraction of opportunity costs.

III. THE REPRESENTATIVE SALMON FARM

To analyse the regional economic impacts of an activity like salmon farming requires that it first be described in terms of total revenue/expenditure and the allocation of each among sectors of the regional economy. Of greatest importance to accurate impact assessment is the division of revenues between export and local sales, and of expenditures and net incomes between regional and non regional recipients.

This step in the analysis was accomplished by interviews with several salmon farming industry participants. These individuals provided both information on their own operations, as well as a general overview of what, in their view, the future salmon farming industry would look like.

Production and financial profiles of several salmon farms were obtained from their owners or managers. In some cases intervewes provided exact revenues or expenditures, and in other cases general planning factors, "Feed is $.90 per finished pound.", "Sales cost is 5% of gross revenue.", etc. Confidentiality commitments preclude identifying the firms supplying this data, or given the fewness of firms, publication of specific data in even masked form. Instead, the revenue/cost profile of a representative operation (table 3.1) was built from the data provided. By design, this profile describes the industry in general, but no firm in particular. In addition, while estimates of profit are sufficiently accurate for regional economic analysis, they should not be considered reliable for investment planning or other purposes.

Industry interviews also suggested that production will include pan size and mature coho, chinook and Atlantic salmon, but that mature (about 9 lb round weight) Atlantic salmon will gain in significance over time. Hence, the profile described in table 3.1 describes the production, revenues and expenditures of a 1,000,000 finished pound Atlantic salmon production facility. This production is assumed to sell entirely into out of state markets at $5.00 per pound. The disbursement of the resulting $5,000,000 in annual revenue is allocated among phases of production (hatchery, fish farm, administration) and among input types (feed, labor, etc).

The extent to which these inputs are supplied locally or from outside the region is the primary determinant of the facilities indirect and induced regional economic impact. The local/import supply factors used here are reported in table 3.2. For some inputs the pattern of regional/import supply was either obvious, or could be reliably determined by interview. Labor is necessarily supplied from within the state and, for the most part, the subject county. Processing of fresh round fish is most conveniently done nearby, certainly in Washington and most likely in the subject county. Packaging materials, freight, and brokerage services for fish shipped out of Seattle will most likely by supplied by in-state, but not in-county firms.

Sources of other inputs are less certain, and may vary over

Table 3.1 Representative Atlantic Salmon Farm Revenues and Costs (thousand dollars)

Production and Revenue

Finished pounds	1,000,000
Price	$5.00
Gross revenue	$5,000,000

Expenditures

Item	Amount	$/lb
Hatchery: Eggs	$300,000	$0.30
Hatchery: Labor	$250,000	$0.25
Hatchery: Other	$50,000	$0.05
Hatchery: Employment	8	
Fish Farm: Labor	$500,000	$0.50
Fish Farm: Other	$450,000	$0.45
Fish Farm Employment	20	
Feed	$900,000	$0.90
Processing	$250,000	$0.25
Packaging	$100,000	$0.10
Freight	$250,000	$0.25
Brokerage	$250,000	$0.25
General Administration	$250,000	$0.25
Administrative Employment	5	
Debt Service	$350,000	$0.35
Equity Return	$1,100,000	$1.10
TOTAL	$5,000,000	$5.00

Table 3.2 Representative Atlantic Salmon Farm
Regional Distribution of Expenditures

	In County		In State	
	Max	Min	Max	Min
Hatchery: Eggs	100%	0%	100%	50%
Hatchery: Labor	100%	100%	100%	100%
Hatchery: Other	50%	25%	75%	50%
Fish Farm: Labor	100%	100%	100%	100%
Fish Farm: Other	50%	25%	75%	50%
Feed	0%	0%	100%	50%
Processing	100%	100%	100%	100%
Packaging	0%	0%	100%	100%
Freight	0%	0%	100%	100%
Brokerage	0%	0%	100%	100%
General Administration	50%	25%	75%	50%
Debt Service	0%	0%	100%	0%
Equity Return	100%	0%	100%	0%

time with the size of the industry, and with other factors. The following maximum and minimum local input factors were adopted for these inputs. Currently, the preponderance of feed is provided by Moore Clark of LaConner (Skagit County) Washington, with some feed imported from Oregon. Washington feed supply is set at 100 % to 50 %, a factor which will depend, among other things, on the future competitive position of Washington suppliers. Egg costs are set at either 100 % Washington and 100 % county (local production) or 50 % Washington (external purchase). Other expenditures and administrative costs are set at 75% to 50% Washington and 50 % to 25 % county supply. Debt service is set at 100 % and 0 % Washington (in or out of state financing), and equity return is set at 100 % Washington 100 % county (local ownership) or 0 % Washington 0 % county (out of state ownership).

IV. REGIONAL ECONOMIC IMPACTS

Regional Economic impacts are computed by allocating the expenditures of the representative salmon farm to appropriate model catagories, and then performing the calculations described in tables 2.3 and 2.4. All results vary depending on whether minimum or maximum state/local supply assumptions are used. County results vary further (although only slightly) as a result of each counties different economic structure. Results are reported in summary form in table 4.1, and in more detail in tables 4.2 (statewide), table 4.3 (Clallam Co.), table 4.4 (Jefferson Co.), table 4.5 (Kitsap Co.), Table 4.6 (San Juan Co.) and table 4.7 (Skagit Co.).

Statewide impacts were based on an industry expansion equal to 5 of the representative salmon farms discussed in the preceeding section. County impacts were based on one such facility in each county. Because of the liniar nature of input-output analysis, the computation of impacts for other industry sizes (combination of facilities) can be accomplished by simple multiplication of these results. That is 2 operations in a county would have exactly twice the county impact of one, and 10 facilities would have twice the state impact of 5.

As described in table 4.1, a 5 million pound Atlantic salmon farming industry (5 representative facilities) would contribute between $38 and $48 million to state output, between $11 and

Table 4.1: Summary of Impacts: 5,000,000 lb Atlantic Salmon Industry in Washington, and Average Results for a 1,000,000 lb Facility in Clallam, Jefferson, Kitsap, San Juan or Skagit County ($ thousands)

	OUTPUT	INCOME	EMPLOYMENT
Maximum			
State	$48,395	$21,412	303
County	$6,812	$2,748	51
Minimum			
State	$38,227	$10,615	257
County	$5,775	$1,132	40

Table 4.2: Detailed Impacts: 5,000,000 lb Atlantic Salmon Production: Washington State (thousand dollars)

Local Supply Sector	Direct Maximum	Direct Minimum	Total Maximum	Total Minimum
Agriculture, Forestry, Fisheries	$1,500	$750	$2,362	$1,255
Mining	$0	$0	$42	$30
Construction	$0	$0	$476	$274
Manufacturing	$6,250	$4,000	$9,011	$5,682
Transport, Comm, Utilities	$3,125	$2,500	$4,897	$3,616
Wholesale Trade	$1,250	$1,250	$1,299	$1,278
Retail Trade	$0	$0	$682	$342
Finance, Insurance, Real Estate	$1,750	$0	$3,968	$1,083
Services	$938	$625	$3,202	$1,869
Federal Government	$0	$0	$22	$10
State and Local Government	$0	$0	$86	$48
Housholds	$9,250	$3,750	$21,412	$10,615
Total Output	$25,000	$25,000	$48,395	$38,227
Employment	161	161	303	257

Table 4.3: Detailed Results: 1,000,000 lb Atlantic Salmon Farm: Clallam County (thousand dollars)

Local Supply Sector	Direct Maximum	Direct Minimum	Total Maximum	Total Minimum
Agriculture, Forestry, Fisheries	$300	$0	$325	$4
Mining			$0	$0
Construction			$36	$17
Manufacturing	$250	$250	$325	$307
Transport, Comm, Utilities	$250	$125	$391	$188
Wholesale Trade	$0	$0	$0	$0
Retail Trade			$142	$59
Finance, Insurance, Real Estate	$0	$0	$261	$107
Services	$125	$63	$415	$186
Federal Government			$2	$1
State and Local Government			$15	$7
Housholds	$1,850	$750	$2,801	$1,171
Total Output	$5,000	$5,000	$6,937	$5,858
Employment	32	32	52	41

Table 4.4: Detailed Results: 1,000,000 lb Atlantic Salmon Farm: Jefferson County (thousand dollars)

Local Supply Sector	Direct Maximum	Direct Minimum	Total Maximum	Total Minimum
Agriculture, Forestry, Fisheries	$300	$0	$321	$6
Mining			$0	$0
Construction			$45	$16
Manufacturing	$250	$250	$291	$281
Transport, Comm, Utilities	$250	$125	$348	$172
Wholesale Trade	$0	$0	$3	$1
Retail Trade			$140	$58
Finance, Insurance, Real Estate	$0	$0	$230	$95
Services	$125	$63	$369	$166
Federal Government			$1	$1
State and Local Government			$16	$7
Housholds	$1,850	$750	$2,786	$1,155
Total Output	$5,000	$5,000	$6,776	$5,770
Employment	32	32	51	40

Table 4.5: Detailed Results: 1,000,000 lb Atlantic Salmon Farm: Kitsap County (thousand dollars)

Local Supply Sector	Direct Maximum	Direct Minimum	Total Maximum	Total Minimum
Agriculture, Forestry, Fisheries	$300	$0	$310	$5
Mining			$0	$0
Construction			$14	$3
Manufacturing	$250	$250	$286	$280
Transport, Comm, Utilities	$250	$125	$309	$154
Wholesale Trade	$0	$0	$1	$0
Retail Trade			$84	$35
Finance, Insurance, Real Estate	$0	$0	$188	$79
Services	$125	$63	$304	$139
Federal Government			$16	$7
State and Local Government			$9	$4
Housholds	$1,850	$750	$2,615	$1,080
Total Output	$5,000	$5,000	$6,361	$5,598
Employment	32	32	42	36

Table 4.6: Detailed Results: 1,000,000 lb Atlantic Salmon Farm: San Juan County (thousand dollars)

	Direct		Total	
Local Supply Sector	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	$300	$0	$343	$8
Mining			$2	$2
Construction			$45	$19
Manufacturing	$250	$250	$313	$284
Transport, Comm, Utilities	$250	$125	$459	$218
Wholesale Trade	$0	$0	$29	$12
Retail Trade			$544	$225
Finance, Insurance, Real Estate	$0	$0	$310	$127
Services	$125	$63	$254	$119
Federal Government			$1	$1
State and Local Government			$35	$14
Housholds	$1,850	$750	$2,957	$1,225
Total Output	$5,000	$5,000	$7,518	$6,068
Employment	32	32	67	46

Table 4.7: Detailed Results: 1,000,000 lb Atlantic Salmon Farm: Skagit County (thousand dollars)

	Direct		Total	
Local Supply Sector	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	$300	$0	$345	$10
Mining			$0	$0
Construction			$24	$10
Manufacturing	$250	$250	$403	$325
Transport, Comm, Utilities	$250	$125	$353	$172
Wholesale Trade	$0	$0	$3	$1
Retail Trade			$76	$30
Finance, Insurance, Real Estate	$0	$0	$155	$60
Services	$125	$63	$292	$130
Federal Government			$0	$0
State and Local Government			$7	$3
Housholds	$1,850	$750	$2,581	$1,027
Total Output	$5,000	$5,000	$6,466	$5,581
Employment	32	32	44	37

$21 million to houshold incomes, and would create between 257 and 303 jobs statewide. Averaging results obtained from individual county models suggests that a single 1 million pound facility would contribute between $5.8 and $6.8 million to county output, between $1.1 and $2.7 million to county houshold income, and would create 40 to 51 jobs within the county .

Table 4.8: 1,000,000 lb Atlantic Salmon Farm, Average County Results (thousand dollars)

	Total Output		Housholds		Employment	
County	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Clallam	$6,937	$5,858	$2,801	$1,171	52	41
Jefferson	$6,361	$5,598	$2,615	$1,080	42	36
Kitsap	$6,776	$5,770	$2,786	$1,155	51	40
San Juan	$7,518	$6,068	$2,957	$1,225	67	46
Skagit	$6,466	$5,581	$2,581	$1,027	44	37
Average	$6,812	$5,775	$2,748	$1,132	$51	$40

V. STATE AND LOCAL FISCAL IMPACTS

The foregoing input-output analysis results provide a basis for the comprehensive assessment of how an expanded salmon farming industry would effect state revenues and expenditures. The required extensions to the input-output model can be identified by examining the major items of revenue and expenditure reported in table 5.1.

There, we see that 71 % of state revenue arises from 4 sources, sales taxes, gross receipts taxes, property taxes, and federal grants, with the remaining 29 % consisting of miscellaneous taxes and revenues. Similarily, 71 % of expenditures are for education (all levels) and human resources (including welfare), with the remaining 29 percent going to other catagories including general government. The general government catagory, however, includes debt service and pension expenditures, many of which could properly be allocated by function to education and human services as well.

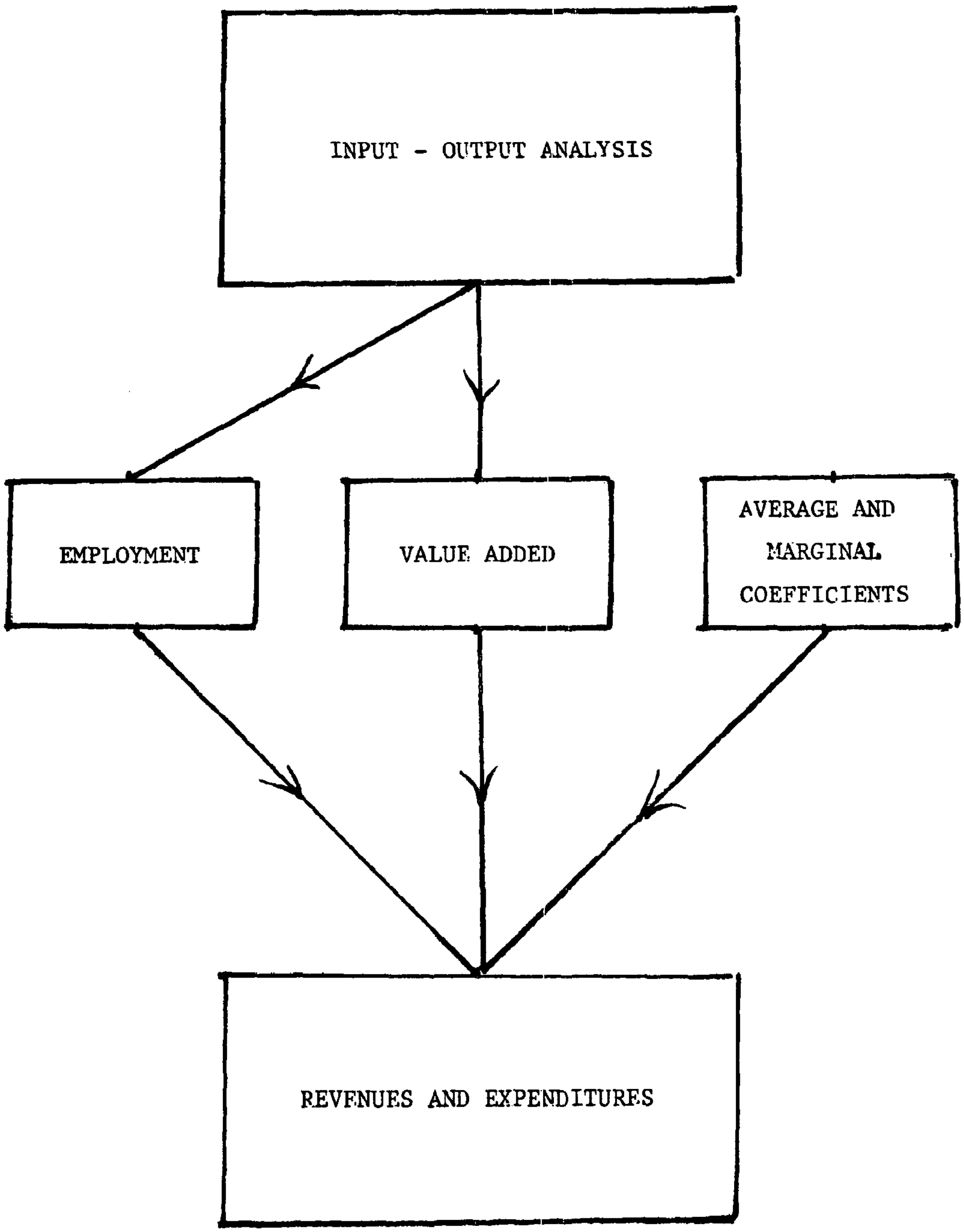
Thus, obtaining a fiscal analysis from input-output results involves relating 5 revenue types and 3 functional expenditure catagories to the economic changes described by the above input-output analysis. Figure 5.1 illustrates, in general, what must be done to accomplish this. The first steps, input-output analysis to produce impacts on output, houshold income and employment, have already been accomplished. This section is

Table 5.1 Distribution of 1982 Washington State Revenues and Expenditures

REVENUE

Item	1982 $000	% Revenue or Expenditure
General and Selective Sales Taxes	$1,901	30%
Gross Receipts Taxes	$635	10%
Property and In Lieu Taxes	$628	10%
Other Taxes	$319	5%
Federal Grants	$1,356	21%
Other Revenue	$1,550	24%
Total Revenue	$6,389	
EXPENDITURE		
Education	$2,751	44%
Human Resources	$1,647	27%
Other Expenditures	$1,796	29%
Total Expenditures	$6,194	

Figure 5.1 Schematic Description of Fiscal Impact Calculation



devoted to the remaining steps; examining possible relationships between those economic variables and revenues/expenditures, choosing coefficients for calculation from among the examined possibilities, and, finally, using sets of chosen coefficients to calculate ranges of fiscal impacts.

The underlying (though not readily observable) economic processes that relate economic expansion (or contraction) to state revenue and cost are postulated to be as follows. Increases in gross output (with houshold income as a proxy variable) increase gross receipts taxes. Increases in houshold income increase consumption which, in turn, increase sales tax revenue. To the extent that both induce increases in taxable assets held by business and consumers, they increase property taxes as well. Depending on the their basis of application, other taxes and revenues also rise.

Expenditures and federal grants are assumed to respond to economic change in a somewhat more complex way. Input-output estimated increases in employment represent jobs filled by some combination of immigrants and unemployed current residents. Increased labor force participation has little, if any, effect on educational and general state expenditures, and may actually reduce human resource expenditures. By contrast, increased population will increase all three expenditure catagories; education due to the children accompanying new immigrants, human resources due to increased welfare and other case loads, and general expenditures for similiar reasons. Federal grants will also increase, to the extent that federal funding formulas include general or target populations.

Figure 5.1 describes the calculations required to implement the above theory of fiscal effect. Included among the standard input-output results are estimates of employment and houshold income (value added) resulting from the siting of salmon farms. The relationship between personal income and revenue is direct; changes in houshold income effect sales taxes, gross receipts taxes, property taxes, and other taxes and revenues. The degree of effect is determined by the estimates reported in tables 5.2 (as estimated from table 5.3 data). The algorithm used to make those calculations is reported in table 5.4. The relationship of employment to expenditures and federal grants has two links; employment to population, and population to enrollment. Each of these is also estimated in table 5.2 and reflected in the algorithm in table 5.4.

Two methods of relating economic change to fiscal magnitudes are reported in table 5.2. In both cases estimates are based on 1970-1985 data, with financial magnitudes expressed in 1982 prices. The first method is that of average ratios. For example, sales tax revenue averaged $.0078 per dollar of personal income, population averaged 2.43 per employee, school enrollment .42 per capita, and state educational expenditure $2,945 per school child. The second method is that of marginal change, based on regression analysis. For example, the marginal change in sales tax revenue with respect to personal income was $.0014, the change in population with respect to employment was 1.52, and the

Table 5.2 Statistics Used to Relate Regional Economic Impacts to Washington State Revenues and Expenditures

Independant Variable (X)	Dependant Variable (Y)	Average Ratio (Y/X)	Coefficient (B) (Y = A+B*X)	T Statistic	R^2
Personal Income	Gross Receipts Taxes	$0.0078	$0.0014	3.14	0.92
Personal Income	Gen & Sel Sales Tax	$0.0331	$0.0062	5.38	0.67
Personal Income	Prop & In Lieu Tax	$0.0071	$0.0006	10.38	0.88
Personal Income	Other Taxes	$0.0048	$0.0010	3.58	0.48
Personal Income	Other Revenue	$0.0164	$0.0052	2.73	0.35
Employment	Population	2.43	1.52	14.96	0.94
Population	Federal Grants	$317	$408	5.26	0.66
Population	Human Resources Exp	$355	$751	11.32	0.9
Population	Other Expenditures	$419	$774	5.42	0.68
Population	Enrollment	0.42			
Enrollment	Education Exp	$2,945			

Table 5.3 Washington State Economic and Fiscal Data: 1970 - 1985 (1982 $)

1 Population (000)
2 Employment (000)
3 Unemployment (000)
4 Children (000)
5 DSHS caseload (000)
6 Personal Income (billions)
7 General and Selective Sales Tax (millions
8 Gross Receipts Tax (millions)
9 Property and In-lieu Exices (millions)
10 Total Tax (millions)
11 Federal Grants (millions)
12 Total Revenue (millions)
13 Education (millions)
14 Human Resources (millions)
15 Total Expenditures (millions)
16 CPI
17 Other Taxes 10-9-8-7 (millions)
18 Other Revenue 12-11-10 (millions)
19 Other Expenditure 15-14-13 (millions)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
70	3413	1285	130	817	166.0	28.5	1815.0	258.3	251.7	2291.6	896.4	4078.8	1910.7	997.7	4284.8	0.925	166.2	890.8	1376.4
71	3436	1259	142	805	200.4	29.8	1633.1	294.6	249.8	2403.7	859.2	3909.7	1831.5	956.4	4107.2	0.965	226.3	646.8	1319.4
72	3430	1297	137	791	202.4	32.1	1584.1	276.0	271.9	2418.4	1157.7	4523.8	1832.1	1133.0	4434.2	1.000	286.3	947.6	1469.0
73	3444	1367	117	788	207.9	36.5	1686.2	307.6	255.1	2505.9	1094.3	4275.8	1731.7	1070.9	4191.1	1.058	257.0	675.6	1388.5
74	3509	1420	109	785	206.3	41.1	1665.3	329.2	161.0	2403.3	1124.7	4545.6	1857.1	1170.5	4412.0	1.164	247.8	1017.6	1384.4
75	3568	1412	149	784	214.5	46.3	1688.4	335.4	256.5	2551.6	1044.8	4222.8	1725.2	1087.4	4098.6	1.253	271.3	626.4	1286.1
76	3635	1481	140	780	253.2	51.9	1816.0	345.7	423.9	2889.0	1284.2	5263.4	2248.5	1351.4	5030.3	1.317	303.4	1090.2	1430.4
77	3715	1544	148	776	245.0	57.7	1787.9	545.7	507.2	3098.1	1214.1	4976.2	2125.8	1277.7	4755.9	1.393	257.3	664.0	1352.4
78	3836	1684	124	769	241.1	67.8	1981.2	597.3	537.8	3383.1	1328.6	5752.1	2397.3	1495.2	5548.9	1.490	266.8	1040.4	1656.3
79	3979	1806	131	764	240.1	78.0	1938.3	649.1	594.5	3444.3	1218.3	5274.2	2198.2	1371.0	5087.9	1.625	262.4	611.7	1518.7
80	4132	1826	156	757	269.1	87.6	1850.5	645.6	608.8	3354.7	1531.2	6113.3	2729.8	1715.9	6247.3	1.790	249.7	1227.4	1801.6
81	4227	1806	190	749	299.6	98.1	1777.2	669.4	631.2	3320.4	1409.2	5626.1	2512.2	1579.2	5749.5	1.945	242.5	896.6	1658.1
82	4264	1779	245	739	254.8	102.9	1901.0	635.0	679.0	3535.0	1355.5	6375.0	2751.5	1646.5	6194.0	2.060	320.0	1484.5	1796.0
83	4285	1838	231	736	249.4	107.7	2232.6	768.6	724.3	4060.2	1307.3	6148.2	2653.6	1587.9	5973.6	2.136	334.7	780.7	1732.1
84	4328	1859	194	741	272.0	113.9	2470.3	756.1	706.6	4273.3	1409.9	7097.8	2868.3	1864.2	7194.6	2.204	340.2	1414.6	2462.1
85	4384	1917	170	749	297.9	126.0	2275.2	780.2	686.3	4081.3	1348.1	6786.4	2742.4	1782.4	6878.9	2.305	339.6	1357.0	2354.1

Table 5.4 Algorithm for Calculating State Revenues and Expenditures From Regional Economic Impacts

PERSONAL INCOME DRIVEN VARIABLES

ITEM	AVERAGE	MARGINAL
1. Gross Receipts Taxes	$0.0078	$0.0078
2. Gen & Selective Sales Tax	$0.0331	$0.0331
3. Property & In Lieu Tax	$0.0071	$0.0071
4. Other Taxes	$0.0048	$0.0048
5. Other Revenue	$0.0164	$0.0164
	0.0692	0.0692
6. Employment >> Population	2.43	2.43
POPULATION DRIVEN VARIABLES		
7. Federal Grants	$317	$317
8. Human Resources Expenditure	$355	$355
9. Other Expenditures	$419	$419
10. Population >> Enrollment	0.42	0.42
ENROLLMENT DRIVEN VARIABLES		
11. Education Expenditure	$2,945	$2,945

Revenue = VA*(1+2+3+4+5) + E*6*7

Expenditure E*6*((8+9)+10*11)

Net = Revenue - Expenditure

E = Employment
VA = Value Added = Personal Income

change in human resource expenditure with respect to population was $751.

Both the average ratio and marginal change method are subject to error. For example, there is considerable evidence that housholds maintain a reasonably stable standard of living over the medium term, adjusting their savings (or dissavings) rate as well as their consumption expenditures in the face of short-term income changes. We would thus expect, (as is observed in table 5.2) that marginal changes in consumption based taxes will be less than average ratios. On the expenditure side fixed program costs will not vary in direct proportion to population or caseload. Thus we again expect marginal effects to be less than average ratios.

That this is not the case in table 5.2 points up the principal defect of the marginal approach. Estimates of marginal change, based on regression analysis can be, (as these estimates undoubtedly are) biased by neglected changes occuring during the period of estimation. Changes effecting revenue would include alteration of tax rates and the basis of their application, both of which have occured in the 1970 -1985 period. Most notably the removal of the sales tax from food. On the expenditure side, bias can result from legislated changes in the scale of state programs and entitlement formulas, as well as changes in population structure. Increased state level school funding, and declines in fecundity between 1970 - 1985 illustrate sources of potential bias in the marginal values reported in table 5.2.

The removal of these and other biases, if possible at all, would require data gathering and statistical analysis beyond the scope of this project. Hence, to give a range of possible fiscal effects we use both average ratios and marginal values to compute fiscal effects. An exception is the exclusive use of average ratios to calculate changes in educational expenditure. Estimated marginal values (regression coefficients) relating children to population, and educational expenditures to children, were both illogical negative values. The first undoubtedly reflects declines in fecundity, and the second changes in the state funding formula.

Table 5.4 describes the algorithm used to calculate fiscal effects. To calculate taxes and other revenues, average and marginal rates were multiplied by maximum and minimum estimates of the statewide value added resulting from a 5,000,000 pound salmon farming industry. Federal grant revenue, human resource expenditures, and other expenditures were similarily calculated by multiplying maximum and minimum employment estimates by the product of population per employee and catagory expenditures per capita. Education expenditures were calculated in a similar manner, with the insertion of enrollment per capita.

Results, reported in table 5.5, indicate that annual state revenues from a 5,000,000 pound industry could range from a high of $2.26 million (maximum impact, average ratio) to a low of $.36 million (minimum impact, marginal value). Expenditures could

Table 5.5 Impacts of a $25,000,000 Salmon Farming Industry on Washington State Revenues and Expenditures

Case	Revenues	Expenditures	Net
Maximum Economic Impact			
Average Calculation	$2,257,105	$1,482,468	$774,637
Marginal Calculation	$598,608	$1,273,621	($675,013)
Minimum Economic Impact			
Average Calculation	$1,201,216	$1,256,711	($55,494)
Marginal Calculation	$362,981	$1,079,668	($716,687)

range from a high of $1.48 million (maximum impact average ratio) to a low of $1.08 million (minimum impact, marginal value).

VI. PROPERTY VALUES

The last empirical research task undertaken in this report is to investigate the economic implications of assertions that salmon farms will, due to negative visual aesthetics effects, reduce adjacent waterfront property values.

It must be emphasised that it is the economic implications of assertions about aesthetic loss and price decline that are being examined, not the assertions themselves. Where the existence of markets, or other circumstances permit the observation of human behavior toward aesthetic resources, the measurement of aesthetic values it theoretically possible and occassionally attempted. However, employment here of the methods used in such empirical inquiries, such as consumer surveys and hedonic pricing, would require far more time and resources than are currently available.

A simpler method is offered instead, which relies only on publically available property value data and simple regression analysis. The results of this analysis are, by means discussed below and in the next section, combined with essentially arbitrary judgments about the aesthetic effect of salmon farms. The purpose of this exercise is to provide an analytical framework within which the results of other research into (or personal opinion concerning) aesthetic effects can be integrated with other economic data to inform siting decisons.

The first step in implementing this approach was to collect the types of data on waterfront property which are available from real estate firms, multiple listing services, and county assessors. Summary statistics on the 335 properties surveyed on this basis are reported in tables 6.1 to 6.7. As indicated in table 6.1, the average value of the 335 properties surveyed was $409 per front foot, with a standard deviation of $209. The lowest average value was in Clallam County $271, and the highest was in San Juan County $506. This pattern, which coincides with views of consulted realtors and assessors, results partly from locational preference for the San Juan Islands, and partly from the greater predominance of lower valued "high bank" waterfront in Clallam County.

Among the classes of values obtained, market values (asked or sold as reported by realtors and multiple listing services) were on average $223 per front foot higher than assessed values, $531 versus $303. This difference was also supported by the experience of realtors and assessors. Current, full market value is the legal standard for property assessment in Washington State. However, the fewness of transactions in rural waterfront areas often makes it difficult for assessors to keep values current in times of price inflation.

Over the entire sample, values of low bank and no bank property were, as expected, the highest of the three catagories, $534 per front foot, versus $396 for medium bank and $312 for high bank.

Finally, an index, called SCORE, was tabulated, as the sum of listed property improvements (other than buildings) and other

Table 6.1 Puget Sound Waterfront Property Front Footage Values

	Assessed	Market	All
	AVERAGE PRICE PER FRONT FOOT		
Puget Sound	$303	$531	$417
Clallam Co	$223	$619	$271
Jefferson Co	$300	$451	$428
Kitsap Co	$437	$364	$425
San Juan Co	375	$614	$506
Skagit Co	$305	$489	$381

	N	AVERAGE PRICE PER FRONT FOOT
All	335	$409
High Bank	116	$312
Medium Bank	50	$396
Low or No Bank	100	$534
Score		
0	110	$324
1+	205	$464
2+	153	$476
3+	101	$462
4+	89	$458
5+	31	$541

Table 6.2 Puget Sound Waterfront Property

Item	Assessed	Market	All
Number	183	142	325
Front Footage			
Maximum	3000	5348	5348
Average	408	198	316
Minimum	50	40	40
Acreage			
Maximum	206.00	264.00	264.00
Average	8.83	3.94	6.69
Minimum	0.33	0.17	0.17
Price			
Maximum	$2,110,000	$3,000,000	$3,000,000
Average	$73,064	$140,223	$102,407
Minimum	$1,700	$10,000	$1,700
Price per Front Foot			
Maximum	$1,665	$1,525	$1,665
Average	$315	$531	$409
Minimum	$9	$72	$9

Table 6.3 Clallam County Waterfront Property

Item	Assessed	Market	All
Number of Prop	36	5	41
Front Footage			
Maximum	1320	209	1320
Average	223	118	210
Minimum	62	80	62
Acreage			
Maximum	11.71	2.00	11.71
Average	2.49	0.82	2.29
Minimum	0.50	0.17	0.17
Price			
Maximum	$72,600	$100,000	$100,000
Average	$34,722	$60,800	$37,903
Minimum	$9,340	$30,000	$9,340
Price per Front Foot			
Maximum	$450	$1,050	$1,050
Average	$223	$619	$271
Minimum	$55	$144	$55

Table 6.4 Jefferson County Waterfront Property

Item	Assessed	Market	All
Number of Prop	10	35	45
Front Footage			
Maximum	320	400	400
Average	147	146	152
Minimum	70	60	60
Acreage			
Maximum	20.00	7.11	20.00
Average	4.48	2.55	3.35
Minimum	0.89	0.17	0.17
Price			
Maximum	$77,440	$105,000	$105,000
Average	$41,429	$58,794	$56,024
Minimum	$17,850	$17,500	$17,500
Price per Front Foot			
Maximum	$360	$907	$907
Average	$300	$451	$428
Minimum	$142	$175	$142

Table 6.5 Kitsap County Waterfront Property

Item	Assessed	Market	All
Number of Prop	40	8	48
Front Footage			
Maximum	540	330	540
Average	179	250	191
Minimum	50	80	50
Acreage			
Maximum	11.14	5.03	11.14
Average	2.74	3.38	2.84
Minimum	0.44	0.30	0.30
Price			
Maximum	$156,500	$150,000	$156,500
Average	$67,960	$73,000	$68,800
Minimum	$7,600	$29,000	$7,600
Price per Front Foot			
Maximum	$802	$900	$900
Average	$437	$364	$425
Minimum	$91	$150	$91

Table 6.6 San Juan County Waterfront Property

Item	Assessed	Market	All
Number of Prop	50	61	111
Front Footage			
Maximum	950	4500	4500
Average	304	339	323
Minimum	100	80	80
Acreage			
Maximum	13.28	264.00	264.00
Average	3.75	10.38	7.39
Minimum	0.36	0.50	0.36
Price			
Maximum	$304,890	$2,000,000	$2,000,000
Average	$97,711	$164,268	$94,648
Minimum	$27,500	$28,500	$27,500
Price per Front Foot			
Maximum	$650	$1,525	$1,525
Average	$375	$614	$506
Minimum	$120	$72	$72

Table 6.7 Skagit County Waterfront Property

Item	Assessed	Market	All
Number of Prop	47	33	80
Front Footage			
Maximum	3000	5348	5348
Average	910	558	765
Minimum	60	40	40
Acreage			
Maximum	206.00	114.00	206.00
Average	25.21	13.00	20.17
Minimum	0.33	0.21	0.21
Price			
Maximum	$2,110,000	$3,000,000	$3,000,000
Average	$165,883	$210,470	$184,275
Minimum	$1,700	$10,000	$1,700
Price per Front Foot			
Maximum	$1,665	$1,500	$1,665
Average	$305	$489	$381
Minimum	$9	$121	$9

positive features. For example, SCORE 3 might be availability to the property of water, telephone and sewer. SCORE 2 might be an access road and included tidelands. No effort was made to assign relative value to the items that where added up to obtain the variable SCORE. Also, of importance to subsequent discussion, computation of SCORE was based entirely on features of the property itself. Comments on the general area (near the golf course, mountian view, etc.) were not counted. Average value increased with the value of SCORE, from $324 for properties with SCORE = 0, to $541 for those with SCORE >= 5.

The above summary statistics suggest a method of "backing into" an estimate of the value of visual aesthetics. As mentioned, the average value of sampled properties was $417 per front foot, with a standard deviation of $290. This standard deviation estimate suggests that, among all properties from which the sample was drawn, about 68 out of any 100 should fall within a price range of $417 +/- $290, or between $127 and $707.

The sample was drawn from areas throughout Puget Sound, presumably including parcels overlooking a wide variety of visual amenities, and disamenities. Thus, perceived differences in the quality of nearby visual amenities must have given rise to at least part of the reported variance in market value. Note, however, that part of the variance in value can also be explained by factors unrelated to view of the immediate area. Data in table 6.1 suggests that such non-aesthetic factors include county, source of price information (assessor or realty firm), bank type (high,low,medium) and SCORE (which by design reflected only the degree of land improvement and/or positive features confined within the parcel itself).

Multiple regression analysis is a statistical procedure in which overall variance in a dependant variable (here price per front foot) is either explained by a computed regression equation, or assigned to the catagory of unexplained residual variance. The summary statistic R^2 measures the proportion of variance explained by the regression equation, the statistic $(1 - R^2)$ then measures unexplained residual variance.

Multiple regression analysis was performed on the property value data set reported in Appendix 1, with the results reported in table 6.8. The regression equation R^2 of .52 suggests that 48 percent of the overall variance in price per front foot remains unexplained.

To express this result in terms of price ranges, consider the previously mentioned one standard deviation range around the overall average price per front foot, \$417 +/- \$290, or \$127 to \$707. If 76 percent of variance remains unexplained, then the unexplained, one standard deviation range is \$417 +/- .48*\$290, or \$278 to \$556. Here we assume some portion of that variance results from differences in visual amenities adjacent to the surveyed properties. In the next section we discuss how this

Table 6.8 Regression Analysis of Puget Sound Waterfront Property Values

Dependant Variable: PFF = Price Per Front Foot, R Square .52
Standard Deviation of PFF $290

Independant Variables	Definitions	Coefficient	T Statistic
	STEPWISE INCLUDED		
Constant:		453.05	17.24
DPT1	Dummy Variable for Asking Price	174.63	6.38
FF	Front Footage Per Property	-0.38	-12.00
PRICE	Price Per Property	0.00	11.37
DCO1	Dummy Variable for Clallam County	120.55	3.60
DBNK1	Dummy Variable for High Bank	-167.61	-5.61
DBNK2	Dummy Variable for Medium Bank	-177.81	-5.75
DPT2	Dummy Variable for Assesed Price	152.9	2.66
DCO2	Dummy Variable for Jefferson County	64.78	2.21
		453.05	17.24
	STEPWISE EXCLUDED		
DCO3	Dummy Variable for Kitsap County	0.07	1.53
DCO4	Dummy Variable for San Juan County	-0.05	-0.94
ACRES	Acres Per Property	0.04	0.52
SCORE	Index of Property Improvements	0.08	1.72

variance range can be combined with the results of regional input-output analysis to perform an overall benefit cost analysis of salmon farm siting decisions.

VII.BENEFIT - COST ANALYSIS OF SALMON FARM SITING DECISIONS

In this concluding section we organize the foregoing results into a framework for evaluation (from a state economic standpoint) of salmon farm siting decisions. Two preliminary steps preceed development of an evaluation algorothim. The first is to convert previously developed economic information into comparable economic values. The second is to relate changes in these values to the specific circumstances of salmon farm siting. Each of these steps is accomplished by discussion of the parameter ranges reported in table 7.1.

Regional economic benefits of salmon farming will accrue to state or county residents during each year of the facilities operation. Adverse visual effects, on the other hand, will cause a one time reduction in property values when the facilities are sited. However, any such reduction in capital value can be expressed as the loss of an annual income equivalent by use of an appropriate interest rate. The economic logic behind making such a conversion derives from the observation that a property owner always has the option of selling his property and earning an annual income from it, as determined by earnings on investments available to him. That he does not sell, suggest that he places at least this annual value on the utility or satisfaction derived from the use of the land in recreational or residential use.

What interest rate should be chosen to reflect this actual

Table 7.1 Input Parameters to Sensitivity Analysis

PARAMETER NAMES	DESCRIPTIONS	High	Low
	RANGES		
A =	HOUSHOLD INCOME	$21,412,000	$10,615,000
B =	OPPORTUNITY COST OF CURRENT EARNINGS	50%	75%
C =	VISUALLY EFFECTED MILES OF WATERFRONT	25	50
D =	SAMPLE STANDARD DEVIATION	$285	$285
F =	% CHANGE IN AESTHETIC INDEX	10%	20%
G =	INTEREST RATE	3%	8%
	CONSTANTS		
D =	SAMPLE STANDARD DEVIATION		$285.
G =	EXPLAINED VARIANCE (R©2)		0.24

or implicit annual income is a matter of considerable discussion among economists. One point upon which they agree, though, is that a "real" interest rate (i.e. financial rate less expected inflation) should be used. Deduction of expected inflation is necessary because the inflation premium in financial rates, which only maintains initial capital value, provides no estimate of actual net earnings. As reported in table 7.1, we adopt a real interest rate range of 3% to 8% to convert property values into annual equivalents comparable to regional economic benefits.

The different alternatives facing waterfront property owners and individuals benefiting from regional economic expansion point up the need for another conversion. Feasable non-recreational/residental uses of rural waterfront property consist primarily of agriculture and forestry, activities that would support only a small fraction of prevailing market prices. Thus, the waterfront property owner has no realistic alternative to simply accepting any loss in value that results from diminished visual asethetics.

By contrast, the houshold incomes earned due to local economic expansion represent payments for labor and other factors of production that have reasonably attractive alternatives. Most workers employed on salmon farms, or in industries supporting them, could find employment elsewere. For these otherwise employable workers; incomes, working conditions or other values achievable in alternative employment comprise a significant share of the value they place on their chosen employment. Alternative value is not, however, likely to exceed value in the chosen occupation, as in that case the rational worker would change jobs.

Alternative value will also fall short of the value of current employment, to the extent that there are costs (and delays) in finding alternative employment, and to the extent that some workers (such as the elderly or unskilled) lack viable alternatives. We adopt an opportunity cost range of 50% to 75% (ie an implicit net value of gross income of 25% to 50%) to reflect the sum of all these differences between gross regional income and opportunity cost.

We now address the task of interpreting the preceeding sections statistical analysis of property values in terms of lost net economic value. For previously stated reasons, we begin by restating our inability to determine, what, if any, negative aesthetic effects can be attributed to salmon farms. The purpose of this report is to work out the economic implications of independantly provided assessments of visual impact, not to directly estimate these in economic or other terms.[3]

Recall the conclusion of section IV, which suggests that the front footage price of 68% (one standard deviation) of the properties from which the sample was drawn should fall within a range computed as follows:

Actual price = regression calculated price +/- unexplained variance (.48) * standard deviation ($290)

For the purposes of this sections benefit cost analysis we posit an aesthetics index, ranging from zero to one, which explains all of that otherwise unexplained variation. By this formulation a property with a zero aesthetics index would fall at the bottom of the one standard deviation range, ie its price would be the regression calculated value less (.48*$290 = $139). A property with an index of 1.0, would fall at the top of that range (within which 68% of properties now fall), ie. as calculated from the regression equation, plus $139. Were some event to change a properties aesthetics index from one (best) to zero (worst) the result would be a loss of $278 per front foot.

We assume that less than a 1 to 0 change in this aesthetics index would result from siting salmon farming facilities. Specifically our benefit cost calculations are based on a 10 % to 20 % range of reductions. These values are, as previously mentioned, posited for illustration, rather than being offered either as the results of this research, or as the judgments of the author.

In addition to a judgment concerning the degree of aesthetic loss (per effected front foot), we need a similar judgment concerning the geographic extent (feet or miles of coastline) over which that adverse effect will extend. Here we assume, subject to the same qualifications as above, a range of 5 to 10 miles per site, or 25 to 50 miles of coastline for a 5 site industry.

The final variable required by the benefit-cost algorithm is gross benefit to the state from economic expansion. For this purpose we enter the statewide maximum and minimum value added estimates of $21.4 and $10.6 million.

The benefit-cost algorithm used to perform sensitivity analysis over the above ranges is reported in table 7.2. Each calculation compares maximum beneficiary willingness to pay (numerator), with the minimum required to compensate loosers (denominator). Maximum beneficiary willingness to pay in this case is the statewide value added contributions of 5 salmon farms, adjusted by an opportunity cost factor. Minimum compensation of losers is the loss of waterfront property value, calculated as discussed above.

A six variable, 64 case, sensitivity model was used to calculate benefit cost ratios for all combinations of the input parameters listed in table 7.1. Results are reported in table 7.3. For the input values and ranges adoped, all cases yield benefit cost ratios in excess of unity. This suggests that, under all circumstances and judgments represented by table 7.1 parameters, beneficiaries from salmon farm siting could more than fully compensate loosers. The maximum ratio, resulting from the most favorable combination of range variables, is 97.11. The least favorable is 2.26. Finally, high and low range results are calculated as the mean value of $21.06 +/- the standard deviation of $19.34. These results range from 40.41 to 1.72.

Thus, under all parameters and parameter combinations examined, siting 5 salmon farms would be in the states economic interest, as this was defined above in terms of beneficiary willingness to pay and amounts required to compensate loosers.

Table 7.2 Sensitivity Analysis Algorithm, and Illustrative Calculation

BCR = ANNUAL BENEFITS/ ANNUAL COSTS =	2.26
ANNUAL BENEFITS = A*(1-B) =	$2,653,750
ANNUAL COSTS = 5280*C*2*D*(1-G)*E*F =	$1,175,962

WHERE:
WHERE:

A =	HOUSHOLD INCOME	$10,615,000
B =	OPPORTUNITY COST OF CURRENT EARNINGS	75%
C =	VISUALLY EFFECTED MILES OF WATERFRONT	50
D =	SAMPLE STANDARD DEVIATION	$290
E =	% CHANGE IN AESTHETIC INDEX	20%
F =	INTEREST RATE	8%
G =	EXPLAINED VARIANCE (R@2)	0.52

Parameter values and ranges are reported in table 7.2.
Full sensitivity results in table 7.3.

Table 7.3 Sensitivity Analysis Results

C	E	D	BCR			
		F >>	3%	3%	3%	3%
		A (millions)	$21	$21	$11	$11
		B >>	50%	75%	50%	75%
25	10%	$290	97.11	48.55	48.14	24.07
25	10%	$290	97.11	48.55	48.14	24.07
25	20%	$290	48.55	24.28	24.07	12.04
25	20%	$290	48.55	24.28	24.07	12.04
50	10%	$290	48.55	24.28	24.07	12.04
50	10%	$290	48.55	24.28	24.07	12.04
50	20%	$290	24.28	12.14	12.04	6.02
50	20%	$290	24.28	12.14	12.04	6.02

C	E	D	BCR			
		F >>	8%	8%	8%	8%
		A (millions)	$21	$21	$11	$11
		B >>	50%	75%	50%	75%
25	10%	$290	36.42	18.21	18.05	9.03
25	10%	$290	36.42	18.21	18.05	9.03
25	20%	$290	18.21	9.10	9.03	4.51
25	20%	$290	18.21	9.10	9.03	4.51
50	10%	$290	18.21	9.10	9.03	4.51
50	10%	$290	18.21	9.10	9.03	4.51
50	20%	$290	9.10	4.55	4.51	2.26
50	20%	$290	9.10	4.55	4.51	2.26

Average	21.06	High range	40.41
Standard	19.34	Low range	1.72
Maximum	97.11		
Minimum	2.26		

Notes

1. British Columbia data was provided by Jim Fraylick, British Columbia Ministry of Agriculture and Fisheries.

2. Washington data was provided by Robert Hoyser, Washington State Department of Natural Resources; and Eric Hurlburt, Washington State Department of Fisheries.

3. Some data and an appraisers judgment concerning the degree and geographic extent of adverse visual and market effect is provided in Alpine Appraisers, 1988. The author of that document concludes that "floating net pens have no effect on upland property values in the areas studied (Peal Passage Mason County, and Rich Passage, Kitsap County). Additionally, the appraiser concludes that "the pens will have minimal, if any, visual impact at distances over 2400 lineal feet.

References

Alpine Appraisal Service. "Influence of Floating Salmon Net Pens on Residential Property Values." Report to the Jamestown Clallam tribe, Sequim, Washington, August 30, 1988.

Richardson, Harry W. Input Output and Regional Economics. (New York: John Wiley and Sons, 1972).

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Washington State, Office of Program Planning and Fiscal Management. Pocket Data Guide. Olympia, WA 1983.

A.1 Puget Sound Waterfront Property Survey.

COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
Clallam	Port Angeles	1.50	100	$45,000	$450	assessed	h	water,pave	67960	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	136	$27,200	$200	assessed				0	Clallam Co Assessor
Clallam	Port Angeles	0.96	100	$35,000	$350	assessed	h	elec,water,ph,pave		4	Clallam Co Assessor
Clallam	Discovery Bay	1.13	136	$27,200	$200	assessed				0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	102	$9,340	$92	assessed	l	tdl,elec,wat,sew,ph,road		6	Clallam Co Assessor
Clallam	W. of Port Angeles	11.26	1320	$72,600	$55	assessed		erosion		0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.09	105	$13,650	$130	assessed	h	elec,ph,access	295	3	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	295	$60,670	$206	assessed	h		1375	0	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	$63,670	$250	assessed	h	elec,ph	1375	2	Clallam Co Assessor
Clallam	Clallam Bay	0.50	121	$24,320	$201	assessed	l	tdl,elec,wat,sew,ph,road	48710	6	Clallam Co Assessor
Clallam	Port Angeles	1.16	100	$45,000	$450	assessed	h	elec,pave		2	Clallam Co Assessor
Clallam	Clallam Bay	0.50	150	$30,150	$201	assessed	l	tdl,elec,wat,sew,ph,road		6	Clallam Co Assessor
Clallam	Port Angeles	1.16	104	$46,800	$450	assessed	h	elec,water,septic,ph,pave	69700	5	Clallam Co Assessor
Clallam	Clallam Bay	0.50	62	$12,660	$204	assessed	l	tdl,elec,wat,sew,ph,road	11820	6	Clallam Co Assessor
Clallam	Clallam Bay	0.50	63	$12,660	$201	assessed	l	tdl,elec,wat,sew,ph,road	30880	5	Clallam Co Assessor
Clallam	W. of Port Angeles	9.05	560	$56,025	$100	assessed	h			0	Clallam Co Assessor
Clallam	Discovery Bay	1.22	200	$27,335	$137	assessed	h			0	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	$31,835	$125	assessed	h	elec, no perk		0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.75	175	$22,750	$130	assessed	h	elec,ph	475	2	Clallam Co Assessor
Clallam	W. of Disc Bay	1.10	100	$13,000	$130	assessed	h	elec,ph,access		3	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	$61,640	$242	assessed		elec,ph,access	61630	4	Clallam Co Assessor
Clallam	W. of Port Angeles	4.48	215	$21,500	$100	assessed	h			0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	63	$12,660	$201	assessed	l	elec,water,sewer,road	36270	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	136	$22,000	$162	assessed				0	Clallam Co Assessor
Clallam	Discovery Bay	1.09	136	$27,200	$200	assessed				0	Clallam Co Assessor
Clallam	Discovery Bay	2.05	150	$52,500	$350	assessed				0	Clallam Co Assessor
Clallam	W. of Port Angeles	11.71	1320	$72,600	$55	assessed		poor terrain		0	Clallam Co Assessor
Clallam	Port Angeles	1.18	90	$40,500	$450	assessed	h	elec,water,septic,ph,pave		5	Clallam Co Assessor
Clallam	Port Angeles	1.44	100	$45,000	$450	assessed	h	elec,water,septic,ph,pave	51920	5	Clallam Co Assessor
Clallam	W. of Port Angeles	4.50	335	$33,535	$100	assessed	h			0	Clallam Co Assessor
Clallam	Port Angeles	1.50	110	$46,750	$425	assessed	h	elec,water,septic,ph,pave	71350	5	Clallam Co Assessor
Clallam	Discovery Bay	1.09	136	$27,200	$200	assessed				0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.23	100	$13,000	$130	assessed		access,easement		2	Clallam Co Assessor
Clallam	Port Angeles	1.37	134	$50,000	$373	assessed	h	elec,water,sep,ph,pave	67990	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	200	$27,135	$136	assessed				0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	99	$19,920	$201	assessed	l	elec,water,sewer,road	66780	4	Clallam Co Assessor
Clallam	W. Ediz Hook	0.17	100	$50,000	$500	market	h	Buildable		1	Sea Ridge Realty
Clallam	The Place Beach	0.75	100	$100,000	$1,000	market	l	lagoon		2	Sea Ridge Realty
Clallam	Freshwater Bay	2.00	209	$30,000	$144	market	h			0	Sea Ridge Realty
Clallam	4 Seasons Ranch	1.00	80	$84,000	$1,050	market	l	Drain field,planned dev,tdlnds		4	Sea Ridge Realty
Clallam	Straits		100	$40,000	$400	market	h	Building lot		1	Sea Ridge Realty
Jefferson	Ft. Flagler	0.89	100	$36,000	$360	assessed	h	easment	33045	4	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.84	200	$67,500	$338	assessed	h		42125	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	3.00	70	$17,850	$255	assessed	l			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.13	100	$36,000	$360	assessed		water,dirt road	9780	2	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.93	240	$77,440	$323	assessed	m	poor access	21285	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	5.00	110	$28,050	$255	assessed	l			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	0.92	100	$35,000	$350	assessed	m			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	5.04	120	$43,000	$358	assessed	m		27030	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	20.00	320	$45,395	$142	assessed	l			0	Jefferson Co Assessor
Jefferson	Squamish Harbor	5.00	110	$28,050	$255	assessed	h			0	Jefferson Co Assessor
Jefferson	E. Hood Canal	0.61	100	$58,000	$580	market	hm	septic,water,road		3	Jefferson Co Realtor
Jefferson	North Beach	0.26	90	$45,000	$500	market	h	water,road,sewer		4	Realty World
Jefferson	Middle Pt.	5.02	121	$46,000	$380	market	h	power,road,need septic,need well		2	Realty World
Jefferson	Squamish Harbor	1.41	105	$45,000	$429	market	lm	sandy beach		1	Jefferson Co Realtor
Jefferson	Mats Mats Bay	1.62	170	$42,500	$250	market	hm	tidelands,power,well		3	Realty World

A.1 Puget Sound Waterfront Property Survey

COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
Jefferson	Oak Bay	2.07	105	$59,500	$567	market	m	easment		1	Jefferson Co Realtor
Jefferson	Marrowstone I.	2.32	148	$45,000	$304	market		power		1	Jefferson Co Realtor
Jefferson	Pt. Ludlow	0.17	60	$43,500	$725	market	n	water,marina rignts		2	Jefferson Co Realtor
Jefferson	Mats Mats Bay	1.61	100	$74,000	$740	market		septic		1	Jefferson Co Realtor
Jefferson	Marrastone I	4.96	300	$65,000	$217	market				0	Jefferson Co Realtor
Jefferson	Toandos Pen.	2.63	185	$49,500	$268	market	m	power,fruit trees		2	Jefferson Co Realtor
Jefferson	Marrowstone I.	3.03	150	$49,000	$327	market		power,septic		2	Jefferson Co Realtor
Jefferson	Quilcene	2.70	100	$82,500	$825	market	n	water,timber,beach		3	Jefferson Co Realtor
Jefferson	Marrastone I	3.26	290	$105,000	$362	market				0	Jefferson Co Realtor
Jefferson	Cape George	0.57	149	$48,000	$322	market	h	water,power,tel,drain field		4	Realty World
Jefferson	Oak Bay	0.95	100	$39,500	$395	market				0	Jefferson Co Realtor
Jefferson	E. Hood Canal	1.00	100	$56,000	$560	market	l	water,power		2	Jefferson Co Realtor
Jefferson	Middle Point	5.20	121	$52,000	$430	market	h	road,need well. need septic		2	Realty World
Jefferson	Admiralty Inlet	0.96	100	$40,000	$400	market	h			0	Jefferson Co Realtor
Jefferson	Hadlock	5.01	400	$92,500	$231	market		tidelands, water, power		3	Jefferson Co Realtor
Jefferson	E. Hood Canal	0.53	75	$68,000	$907	market	h	easment		1	Jefferson Co Realtor
Jefferson	E. Hood Canal	2.05	118	$51,000	$432	market	m	perk problem.		0	Jefferson Co Realtor
Jefferson	Hood Canal	2.63	185	$45,000	$243	market	m	tidelands,road,power,perks,		4	Realty World
Jefferson	Straits	3.00	136	$49,500	$364	market		well		1	Jefferson Co Realtor
Jefferson	Marrowstone I.	0.86	100	$75,000	$750	market	l	septic		1	Jefferson Co Realtor
Jefferson	Marrowstone I.	3.36	200	$99,500	$498	market		power		1	Jefferson Co Realtor
Jefferson	Oak Head	7.11	200	$69,800	$349	market	h	power		1	Jefferson Co Realtor
Jefferson	Marrowstone I.	3.36	200	$99,500	$498	market	m	tidelands,well,power,tel		4	Realty World
Jefferson	Middle Pt.	5.30	121	$52,500	$434	market	h	power,road,need well,need septic		2	Realty World
Jefferson	Tarboo Bay	1.23	100	$17,500	$175	market	n	spring		1	Jefferson Co Realtor
Jefferson	E. Hood Canal	3.47	200	$48,000	$240	market	h	power		1	Jefferson Co Realtor
Jefferson	Gardiner	3.20	171	$79,000	$462	market	h	power,water,timber		4	Realty World
Jefferson	Discovery Bay	2.52	100	$75,000	$750	market	l			0	Jefferson Co Realtor
Jefferson	Middle Pt.	5.02	121	$46,000	$380	market	h	power,road,need well,need septic		2	Realty World
Jefferson	Cape George	0.40	90	$45,000	$500	market	h	power, well		2	Jefferson Co Realtor
Kitsap	Poulsbo	2.70	175	$52,500	$300	assessed	le	BXPWFAX		3	Kitsap Co Assessor
Kitsap	Fletcher Bay	4.67	220	$107,350	$488	assessed	h	BSPWFGX	62540	4	Kitsap Co Assessor
Kitsap	Fletcher Bay	0.88	70	$40,390	$577	assessed	le	XXNXZXX		0	Kitsap Co Assessor
Kitsap	Eglon	0.46	50	$7,600	$152	assessed	h	XSNWFGX		0	Kitsap Co Assessor
Kitsap	Eglon	0.56	60	$9,120	$152	assessed	h	XSNWFGX		0	Kitsap Co Assessor
Kitsap	Colvos Passage	2.50	210	$42,000	$200	assessed	h	GSNWFGE		2	Kitsap Co Assessor
Kitsap	Poulsbo	0.53	100	$30,000	$300	assessed	le	GXPWFFX		2	Kitsap Co Assessor
Kitsap	Vinland	1.38	155	$108,810	$702	assessed	le	BX(PC)CAGX	90860	5	Kitsap Co Assessor
Kitsap	Vinland	0.79	120	$96,240	$802	assessed	le	BX(PC)CAGX	65360	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	1.97	160	$92,090	$576	assessed	le	GX(PC)CFGE	39220	5	Kitsap Co Assessor
Kitsap	Colvos Passage	5.07	330	$50,160	$152	assessed	h	B(SW)PWFGX		3	Kitsap Co Assessor
Kitsap	Tekiu Pt.	5.97	425	$97,150	$229	assessed	h	GSPCFGX		2	Kitsap Co Assessor
Kitsap	Vinland	2.36		$110,400		assessed	le	BX(PC)CAGX	41430	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.77	205	$138,780	$677	assessed	le	BX(PC)CWAX	34280	5	Kitsap Co Assessor
Kitsap	Colvos Passage	5.08	142	$46,434	$327	assessed	le	GXNXXGE		2	Kitsap Co Assessor
Kitsap	Vinland	3.94	200	$100,400	$502	assessed	le	GX(PC)CAGE	44010	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	1.47	73	$53,020	$726	assessed	le	BX(PC)CFGE	95230	6	Kitsap Co Assessor
Kitsap	Eglon	1.88	100	$9,100	$91	assessed	h	XSNWFGX		0	Kitsap Co Assessor
Kitsap	Eglon	2.02	170	$21,250	$125	assessed	le	DXNXXXX		1	Kitsap Co Assessor
Kitsap	Fletcher Bay	3.80	210	$156,500	$745	assessed	h	BS(PCpXFGX	146150	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	2.61	150	$101,050	$674	assessed	le	GX(PW)XAXE		4	Kitsap Co Assessor
Kitsap	Vinland	0.86	100	$80,200	$802	assessed	le	BXPCAGX	113380	4	Kitsap Co Assessor
Kitsap	Tekiu Pt.	8.49	300	$101,980	$340	assessed	le	GX(PC)CAGX	182700	4	Kitsap Co Assessor
Kitsap	Colvos Passage	3.26	200	$40,000	$200	assessed	h	USNWFGE		1	Kitsap Co Assessor
Kitsap	Colvos Passage	8.18	220	$77,440	$352	assessed	le	XX(PC)CFGE		4	Kitsap Co Assessor
Kitsap	Eglon	2.38	260	$31,200	$120	assessed	h	XSNWFGX		0	Kitsap Co Assessor

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COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
Kitsap	Fletcher Bay	1.61	89	$59,260	$666	assessed	h	GS(PC)WFGE	69930	4	Kitsap Co Assessor
Kitsap	Tekiu Pt.	11.14	540	$102,310	$189	assessed	le	GXNWFGX		1	Kitsap Co Assessor
Kitsap	Colvos Passage	8.09	285	$86,070	$302	assessed	h	USNWXGE		1	Kitsap Co Assessor
Kitsap	Vinland	0.66	100	$80,200	$802	assessed	le	BX(PC)CAGX	134180	5	Kitsap Co Assessor
Kitsap	Poulsbo	0.60	116	$37,450	$323	assessed	le	GX(PC)CFAE	59100	5	Kitsap Co Assessor
Kitsap	Vinland	0.59	110	$88,220	$802	assessed	le	BX(PC)CAGX	72370	5	Kitsap Co Assessor
Kitsap	Colvos Passage	1.27	100	$20,200	$202	assessed	h	USNWFGE		1	Kitsap Co Assessor
Kitsap	Eglon	5.30	510	$73,500	$144	assessed	h	XSNWFGX		0	Kitsap Co Assessor
Kitsap	Poulsbo	0.50	97	$63,240	$652	assessed	le	BX(PC)CGGX		5	Kitsap Co Assessor
Kitsap	Poulsbo	0.60	130	$91,260	$702	assessed	le	B(PC)CGGX	25280	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.30	100	$35,000	$350	assessed	le	BX(PC)CFAX	30350	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.11	115	$80,530	$700	assessed	le	BX(PC@CGAX	102990	5	Kitsap Co Assessor
Kitsap	Poulsbo	0.44	90	$36,000	$400	assessed	le	GXPCFGX		2	Kitsap Co Assessor
Kitsap	Poulsbo	0.68	160	$64,000	$400	assessed	le	GX(PC)CFAX	114510	4	Kitsap Co Assessor
Kitsap	Stavis Bay Road	5.00	330	$49,500	$150	market	he	phone, no elec		1	Coldwell Banker
Kitsap	Stavis Bay Road	5.03	330	$62,500	$189	market	he	power,phone		2	Coldwell Banker
Kitsap	Stavis Bay Road	5.00	330	$65,000	$197	market	he	elec,phone, no water		2	Coldwell Banker
Kitsap	Stavis Bay Road	5.00	330	$150,000	$455	market	l	power,phone,septic,well		4	Coldwell Banker
Kitsap	Stavis Bay Road	5.00	330	$70,000	$212	market	he	elec,phone,no water		2	Coldwell Banker
Kitsap	Big Beef Harbor	0.50	104	$29,000	$279	market	m	elec,phone,needs well		2	Coldwell Banker
Kitsap	Rich Passage	0.30	80	$72,000	$900	market	l	elec,phone,water		3	Coldwell Banker
Kitsap	Olympic View Road	1.23	163	$86,000	$528	market	he	elec,phone, no water		2	Coldwell Banker
San Juan	San Juan W.	9.54	770	$304,890	$396	assessed	m		59400	4	San Juan Co Assessor
San Juan	Shaw S	1.38	310	$118,050	$381	assessed	l	tidelands	16500	4	San Juan Co Assessor
San Juan	Orcas	1.56	210	$90,510	$431	assessed	m	tidelands		1	San Juan Co Assessor
San Juan	Shaw N	4.37	315	$94,500	$300	assessed	l		69720	4	San Juan Co Assessor
San Juan	Lopez W	2.81	315	$94,500	$300	assessed	h			4	San Juan Co Assessor
San Juan	Shaw N	0.57	157	$54,950	$350	assessed	m		24200	4	San Juan Co Assessor
San Juan	Lopez E	0.43	270	$33,750	$125	assessed	m			0	San Juan Co Assessor
San Juan	Shaw S	4.9	740	$155,500	$210	assessed	h		214690	4	San Juan Co Assessor
San Juan	Orcas	3.02	310	$62,000	$200	assessed	m			0	San Juan Co Assessor
San Juan	Lopez W	12.7	400	$90,010	$225	assessed	m			0	San Juan Co Assessor
San Juan	San Juan SW	1.91	213	$128,850	$605	assessed	m	tidelands	7220	5	San Juan Co Assessor
San Juan	Shaw SE	1.18	100	$60,000	$600	assessed	m		25040	4	San Juan Co Assessor
San Juan	Orcas E	5.71	290	$96,450	$333	assessed	h		1670	0	San Juan Co Assessor
San Juan	Shaw N	2.83	300	$90,000	$300	assessed	m		76940	4	San Juan Co Assessor
San Juan	Shaw SE	1.84	150	$83,400	$556	assessed	m	tidelands	13780	5	San Juan Co Assessor
San Juan	Shaw W	6.44	665	$160,290	$241	assessed	l		1880	0	San Juan Co Assessor
San Juan	Lopez N	0.38	110	$41,250	$375	assessed	m	tidelands	16750	5	San Juan Co Assessor
San Juan	Orcas E	5.09	360	$112,050	$311	assessed	m		121970	4	San Juan Co Assessor
San Juan	Lopez W	12.29	590	$154,990	$263	assessed	h			0	San Juan Co Assessor
San Juan	San Juan W.	2.05	200	$110,000	$550	assessed	h			0	San Juan Co Assessor
San Juan	Lopez E	0.68	120	$66,720	$556	assessed	m	tidelands	42410	5	San Juan Co Assessor
San Juan	Lopez E	2.5	140	$84,000	$600	assessed	m		133790	4	San Juan Co Assessor
San Juan	Lopez E	0.36	100	$27,500	$275	assessed	m			0	San Juan Co Assessor
San Juan	Lopez S	9.75	440	$150,200	$341	assessed	m			0	San Juan Co Assessor
San Juan	Lopez NW	5.1	290	$74,550	$257	assessed	h		2460	0	San Juan Co Assessor
San Juan	Shaw N	0.81	200	$70,000	$350	assessed	m		117940	4	San Juan Co Assessor
San Juan	Orcas SE	4.04	265	$90,550	$342	assessed	m			0	San Juan Co Assessor
San Juan	Shaw S	2.7	950	$142,500	$150	assessed	h			0	San Juan Co Assessor
San Juan	Orcas E	10.65	535	$151,650	$283	assessed	h			0	San Juan Co Assessor
San Juan	Orcas E	1.62	150	$78,750	$525	assessed	h		40280	4	San Juan Co Assessor
San Juan	Lopez E	2.2	100	$65,000	$650	assessed	m		71430	4	San Juan Co Assessor
San Juan	San Juan W.	1.8	160	$104,000	$650	assessed	m	tidelands	81360	5	San Juan Co Assessor
San Juan	Orcas SE	4.02	250	$108,050	$432	assessed	m		9220	4	San Juan Co Assessor
San Juan	Shaw N	2.1	510	$61,200	$120	assessed	m		2550	0	San Juan Co Assessor

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COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
San Juan	San Juan W.	2.23	210	$105,000	$500	assessed	h		192730	4	San Juan Co Assessor
San Juan	Orcas	1.66	200	$86,200	$431	assessed	h	tidelands	160840	5	San Juan Co Assessor
San Juan	Shaw N	7.34	435	$130,500	$300	assessed	m		88810	4	San Juan Co Assessor
San Juan	Orcas N	1.2	150	$75,000	$500	assessed	l			0	San Juan Co Assessor
San Juan	Lopez E	0.83	135	$75,060	$556	assessed	l	tidelands		1	San Juan Co Assessor
San Juan	Shaw W.	13.28	290	$172,400	$594	assessed	l		65140	4	San Juan Co Assessor
San Juan	Lopez W	1.89	120	$61,280	$511	assessed	h		21690	4	San Juan Co Assessor
San Juan	Orcas N	3.41	165	$80,880	$490	assessed	l			0	San Juan Co Assessor
San Juan	Orcas E	5.1	395	$128,760	$326	assessed	h		99290	4	San Juan Co Assessor
San Juan	Orcas W	0.66	220	$33,000	$150	assessed	h			0	San Juan Co Assessor
San Juan	Lopez N	0.65	170	$52,050	$306	assessed	h		156320	4	San Juan Co Assessor
San Juan	Lopez E	3.15	300	$112,500	$375	assessed	l		58610	4	San Juan Co Assessor
San Juan	Shaw W	6.77	380	$166,500	$438	assessed	m			0	San Juan Co Assessor
San Juan	Shaw S	1.18	278	$113,000	$406	assessed	l	tidelands	4310	4	San Juan Co Assessor
San Juan	Orcas	1.4	355	$62,130	$175	assessed	m			0	San Juan Co Assessor
San Juan	Orcas E	5.1	270	$97,200	$360	assessed	h			0	San Juan Co Assessor
San Juan	Mosquito Pass	5.00	367	$215,000	$586	market	l			0	Island Computer Services
San Juan	Kanaka Bay	1.25	160	$110,000	$688	market				0	Island Computer Services
San Juan	Orcas, Diamond Pt.	264.00	4500	$2,000,000	$444	market	hm			0	Dockside Property
San Juan	Yacht Haven	0.70	140	$89,500	$639	market	n	pwr,beach		2	Island Computer Services
San Juan	Pear Pt.	1.19	184	$112,500	$611	market	m	pwr,wtr		2	Island Computer Services
San Juan	Griffin Bay	3.78	265	$224,000	$845	market				0	Island Computer Services
San Juan	Sunset Pt.	0.50	125	$95,000	$760	market				0	Island Computer Services
San Juan	San Juan	0.50	130	$64,500	$496	market				0	Island Computer Services
San Juan	San Juan	2.30	240	$95,000	$396	market		pwr,wtr		2	Island Computer Services
San Juan	Neil Bay	0.74	100	$62,500	$625	market	n	pwr,wtr,spt		3	Island Computer Services
San Juan	Cape San Juan	0.50	80	$39,950	$499	market		prc,pwr,wtr		3	Island Computer Services
San Juan	Cape San Juan	0.50	100	$69,500	$695	market		prc,pwr,spt		3	Island Computer Services
San Juan	San Juan	1.42	185	$120,000	$649	market	l	pwr,wtr		2	Island Computer Services
San Juan	SJ Cattle Point	90.95	600	$795,000	$1,325	market	lm	power,water,park,gravel beach		5	Dockside Property
San Juan	Deadman Bay	5.10	1005	$157,500	$157	market	m			0	Island Computer Services
San Juan	Friday Island	0.70	100	$69,500	$695	market				0	Island Computer Services
San Juan	Garrison Bay	56.00	200	$225,000	$1,125	market		timber,pwr		2	Island Computer Services
San Juan	University Heights	16.60	250	$139,900	$560	market				0	Island Computer Services
San Juan	Cattle Point	1.00	165	$65,000	$394	market		pwr,wtr		2	Island Computer Services
San Juan	Yacht Haven	7.60	1178	$84,500	$72	market	n	pwr		1	Island Computer Services
San Juan	SJ, Friday Harbor	3.00	450	$185,000	$411	market	lm	beach/cove		2	Dockside Property
San Juan	San Juan	2.64	210	$95,000	$452	market		pwr,wtr		2	Island Computer Services
San Juan	San Juan	5.46	340	$110,000	$324	market		pwr		1	Island Computer Services
San Juan	Roche Harbor	1.25	160	$208,000	$1,300	market	l	Moorage		1	Island Computer Services
San Juan	University Heights	0.50	100	$58,500	$585	market		pwr,wtr,		2	Island Computer Services
San Juan	Stuart I.	9.92	480	$75,000	$156	market				0	Island Computer Services
San Juan	Shaw	2.00	225	$100,000	$444	market	l	pwr		1	Island Computer Services
San Juan	Mitchell Bay	5.15	625	$290,000	$464	market				0	Island Computer Services
San Juan	Wescott Bay	0.50	100	$72,500	$725	market	l	pwr,wtr		2	Island Computer Services
San Juan	Roche Harbor	1.00	175	$198,000	$1,131	market	l	pwr		1	Island Computer Services
San Juan	Eagle Cove	1.00	100	$57,500	$575	market		pwr,ph		2	Island Computer Services
San Juan	Cattle Pt.	0.88	120	$65,000	$542	market		pwr,wtr		2	Island Computer Services
San Juan	Mineral Heights	0.50	140	$33,000	$236	market		pwr,wtr,		2	Island Computer Services
San Juan	Davidson Head	0.50	100	$75,000	$750	market	m	wtr		1	Island Computer Services
San Juan	San Juan	1.00	130	$85,000	$654	market	n			0	Island Computer Services
San Juan	Neil Bay	0.62	100	$115,000	$1,150	market	n	pwr,wtr		2	Island Computer Services
San Juan	Stuart I.	1.00	112	$28,500	$254	market	lm			0	Island Computer Services
San Juan	Griffin Bay	2.25	145	$124,500	$859	market	m	pwr		1	Island Computer Services
San Juan	Deadman Bay	5.30	780	$158,500	$203	market	m	pwr		1	Island Computer Services
San Juan	Cape San Juan	0.70	100	$79,000	$790	market		dock,pool		2	Island Computer Services

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COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
San Juan	Orcas	0.50	100	$85,000	$850	market		pwr,wtr		2	Island Computer Services
San Juan	Eagle Cove	0.80	150	$79,500	$530	market	h	pwr,wtr		2	Island Computer Services
San Juan	San Juan	1.61	375	$210,000	$560	market	l			0	Island Computer Services
San Juan	Rocky Bay	3.11	240	$149,500	$623	market		pwr		1	Island Computer Services
San Juan	Griffin Bay	0.75	100	$89,500	$895	market		pwr,cove		2	Island Computer Services
San Juan	Davidson Head	0.50	100	$75,000	$750	market		pwr,wtr		2	Island Computer Services
San Juan	Hannah Heights	1.00	200	$69,500	$348	market		prc,pwr,wtr,spt		4	Island Computer Services
San Juan	Wescott Bay	0.50	100	$76,500	$765	market		pwr,wtr,spt		3	Island Computer Services
San Juan	Reid Harbor	5.12	300	$65,000	$217	market	m	dock		1	Island Computer Services
San Juan	Wescptt Bay	0.70	140	$75,000	$536	market	l			0	Island Computer Services
San Juan	San Juan	15.20	380	$135,000	$355	market		pwr		1	Island Computer Services
San Juan	University Heights	0.50	100	$120,000	$1,200	market	l			0	Island Computer Services
San Juan	San Juan I	5.00	700	$75,000	$107	market				0	Island Computer Services
San Juan	San Juan	79.25	360	$549,000	$1,525	market	m	pwr		1	Island Computer Services
San Juan	San Juan	0.89	185	$185,000	$1,000	market	m	pwr		1	Island Computer Services
San Juan	San Juan	3.87	600	$180,000	$300	market	m	pwr,wtr,spt		3	Island Computer Services
San Juan	S. End	1.00	200	$76,500	$383	market		pwr,wtr		2	Island Computer Services
San Juan	Wescott Bay	5.00	755	$187,500	$248	market	l	beach		1	Island Computer Services
San Juan	Griffin Bay	1.50	120	$99,500	$829	market	m	pwr		1	Island Computer Services
San Juan	Eagle Pt.	6.17	375	$174,500	$465	market	h	pwr,wtr		2	Island Computer Services
San Juan	Limestone	5.00	310	$217,000	$700	market		wtr,pwr		2	Island Computer Services
Skagit	E Guemes Ch	9.6	700	$31,300	$45	assessed	h	road	34200	4	Skagit Co Assessor
Skagit	Burrows Bay	5	2000	$35,500	$18	assessed	h			0	Skagit Co Assessor
Skagit	Padilla Bay	26	1600	$90,000	$56	assessed	h	road		1	Skagit Co Assessor
Skagit	Padilla Bay	40.68	1300	$18,900	$15	assessed	l	road		1	Skagit Co Assessor
Skagit	Padilla Bay	1.5	200	$1,700	$9	assessed	l	water	8000	4	Skagit Co Assessor
Skagit	Ship Harbor	7.09	800	$48,900	$61	assessed	m	road,water,septic	75900	4	Skagit Co Assessor
Skagit	Padilla Bay	47.75	1600	$36,800	$23	assessed	h	water,septic,road		3	Skagit Co Assessor
Skagit	Bellingham Bay	3.74	200	$85,860	$429	assessed	l	water,septic,road		3	Skagit Co Assessor
Skagit	Rosario St	55.1	1400	$88,930	$64	assessed	h			0	Skagit Co Assessor
Skagit	Sinclair I.	28.75	1600	$119,380	$75	assessed	h			0	Skagit Co Assessor
Skagit	Bellingham Ch	19.14	320	$38,200	$119	assessed	h	road		1	Skagit Co Assessor
Skagit	Padilla Bay	35.8	1900	$249,270	$131	assessed	h	road		1	Skagit Co Assessor
Skagit	Padilla Bay	34.78	1000	$20,000	$20	assessed	l			0	Skagit Co Assessor
Skagit	Rosario St	4	100	$45,800	$458	assessed	h	easment,septic,water, road	51700	4	Skagit Co Assessor
Skagit	Rosario St	0.38	110	$60,500	$550	assessed	l	road,septic,water	37200	4	Skagit Co Assessor
Skagit	Bellingham Ch	26.13	60	$99,900	$1,665	assessed	l	water,road		2	Skagit Co Assessor
Skagit	Sinclair I.	36.34	1300	$174,400	$134	assessed	h	road		1	Skagit Co Assessor
Skagit	Guemes Ch	14.52	440	$217,800	$495	assessed	l			0	Skagit Co Assessor
Skagit	Padilla Bay	5.15	1450	$24,210	$17	assessed	h			0	Skagit Co Assessor
Skagit	Rosario St	50	1600	$85,850	$54	assessed	l			0	Skagit Co Assessor
Skagit	Rosario St	0.65	79	$43,400	$549	assessed	h	road,water,septic	29600	4	Skagit Co Assessor
Skagit	Rosario St	0.33	63	$34,650	$550	assessed	l	easment,septic,water	41100	4	Skagit Co Assessor
Skagit	Bellingham Bay	2.15	100	$57,280	$573	assessed	l	water,septic,road		3	Skagit Co Assessor
Skagit	Sinclair I.	30.8	1500	$77,000	$51	assessed	h			0	Skagit Co Assessor
Skagit	Bellingham Bay	2.72	122	$64,990	$533	assessed	m	road	93000	4	Skagit Co Assessor
Skagit	Rosario St	0.39	250	$300,000	$1,200	assessed	l	septic,water,road		3	Skagit Co Assessor
Skagit	Bellingham Ch	14.26	1700	$28,500	$17	assessed	m	road		1	Skagit Co Assessor
Skagit	Sinclair I.	9.82	660	$36,930	$56	assessed	h	road,water,septic		3	Skagit Co Assessor
Skagit	E Guemes Ch	10.5	400	$31,500	$79	assessed	h	septic,water		2	Skagit Co Assessor
Skagit	Guemes Ch	0.6	130	$122,100	$939	assessed	l	septic,water,road	67700	4	Skagit Co Assessor
Skagit	Sinclair I.	6	770	$75,700	$98	assessed	h	road,water,septic	90800	4	Skagit Co Assessor
Skagit	Bellingham Ch	18.6	450	$46,500	$103	assessed	h	road		1	Skagit Co Assessor
Skagit	Sinclair I.	29.05	3000	$139,400	$46	assessed	h	road		1	Skagit Co Assessor
Skagit	Bellingham Ch	26.41	1400	$106,400	$76	assessed	m	road		1	Skagit Co Assessor
Skagit	Padilla Bay	11	500	$17,600	$35	assessed	l			0	Skagit Co Assessor

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COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PPRICE FTYPE	BANK	FEATURES	BUILDINGS	SCORE	SOURCE
Skagit	Burrows Bay	206	1900	$2,110,000	$1,111	assessed	l	road,water,septic		3	Skagit Co Assessor
Skagit	Bellingham Bay	1.35	66	$20,860	$316	assessed	h	road		1	Skagit Co Assessor
Skagit	Sinclair I.	14.19	1400	$35,400	$25	assessed	m			0	Skagit Co Assessor
Skagit	Secret Harbor	10.75	1400	$26,800	$19	assessed	h			0	Skagit Co Assessor
Skagit	Bellingham Bay	34	2400	$37,400	$16	assessed	l			0	Skagit Co Assessor
Skagit	Padilla Bay	43.68	1400	$20,300	$15	assessed	l			0	Skagit Co Assessor
Skagit	Guemes Ch	17.15	790	$514,500	$651	assessed	l	road		1	Skagit Co Assessor
Skagit	Bellingham Bay	3.53	187	$82,090	$439	assessed	h	water,septic,road	21700	4	Skagit Co Assessor
Skagit	Burrows Bay	3.92	145	$98,000	$676	assessed	h			0	Skagit Co Assessor
Skagit	Ship Harbor	7.5	400	$15,000	$38	assessed	h	water,septic,road		3	Skagit Co Assessor
Skagit	Burrows Bay	53.6	1400	$86,510	$62	assessed	l			0	Skagit Co Assessor
Skagit	Ship Harbor	8.86	500	$17,700	$35	assessed	h	road		1	Skagit Co Assessor
Skagit	W. Fidalgo	1.68	197	$210,000	$1,066	market	l			0	Coldwell Banker
Skagit	Guemes	1.81	500	$71,000	$142	market	hm			0	Coldwell Banker
Skagit	Coronet Bay	0.90	144	$60,000	$417	market				0	Skagit Co. MLS
Skagit	Fidalgo	4.00	225	$99,000	$440	market				0	Skagit Co. MLS
Skagit	E. Fidalgo	0.22	96	$65,000	$677	market	he			0	Coldwell Banker
Skagit	Allen I.	20.00	660	$220,000	$333	market	hm			0	Coldwell Banker
Skagit	Allen Island	10.50	700	$135,000	$193	market				0	Skagit Co. MLS
Skagit	W. Fidalgo	0.60	133	$74,500	$560	market	he			0	Coldwell Banker
Skagit	W.Fidalgo	1.23	185	$134,500	$727	market	m			0	Coldwell Banker
Skagit	Sinclair	0.24	75	$10,000	$133	market	hm			0	Coldwell Banker
Skagit	Quiet Cove	0.50	100	$77,000	$770	market	l	road,water,tidelands		3	Fidalgo Realty
Skagit	S. Guemes	2.30	100	$89,000	$890	market	h			0	Coldwell Banker
Skagit	NE Guemes	1.00	220	$110,000	$500	market	m			0	Coldwell Banker
Skagit	W. Fidalgo	0.55	150	$58,000	$387	market	m			0	Coldwell Banker
Skagit	Pear Tree Cove	8.00	700	$85,000	$121	market				0	Skagit Co. MLS
Skagit	Fidalgo	20.00	1100	$200,000	$182	market				0	Skagit Co. MLS
Skagit	W.Fidalgo	0.78	184	$114,500	$622	market	hm			0	Coldwell Banker
Skagit	Dewey Beach	0.40	100	$17,000	$170	market	m	road,water		2	Coldwell Banker
Skagit	Sinclair	44.00	1400	$224,500	$160	market	m			0	Coldwell Banker
Skagit	Dec. Pass	0.69	150	$75,000	$500	market	he	tidelands		1	Coldwell Banker
Skagit	Similk Bay	0.21	100	$65,000	$650	market	h	water		1	Southside Realty
Skagit	W. Fidalgo	1.09	100	$78,500	$785	market	hm			0	Coldwell Banker
Skagit	Fidalgo	8.15	750	$177,000	$236	market				0	Skagit Co. MLS
Skagit	Sinclair E.	82.00	1336	$200,000	$150	market	hm			0	Coldwell Banker
Skagit	Cypress	5.00	330	$49,500	$150	market	h			0	Coldwell Banker
Skagit	Guemes I.	4.00	400	$136,500	$341	market	l	beach		2	Fidalgo Realty
Skagit	Skyline	0.25	80	$80,000	$1,000	market	l	extensive prep. development		2	Skyline Realty
Skagit	Deception Pass	0.30	130	$75,000	$577	market	h	water		1	Southside Realty
Skagit	Guemes	114.00	5348	$3,000,000	$561	market	he	timber		1	Coldwell Banker
Skagit	Burroughs Bay	8.00	375	$295,000	$787	market	h			0	Southside Realty
Skagit	Fidalgo	86.00	2230	$590,000	$265	market				0	Skagit Co. MLS
Skagit	Fidalgo	0.30	40	$60,000	$1,500	market				0	Skagit Co. MLS
Skagit	Sinclair	0.22	75	$10,000	$133	market	hm			0	Coldwell Banker

RESPONSE TO COMMENTS

1. GENERAL

Public comments on the appendix titled "The Economics of Salmon Farming" are grouped for response under appropriate headings of that document. Before turning to specific discussion, though, a comment is in order concerning the scope of the economic study that was defined by responsible Washington State officials and represented to the public in the lead paragraph of the executive summary.

"The report examines three economic issues arising from recent growth in Washington's salmon farming industry. The first issue is potential gains in output, income, and employment to the economies of the state and to selected counties. The second is impact on revenues and expenditures of state government, and the third is implications for real estate values of various (externally provided) assumptions concerning visual impacts of salmon farming facilities."

The report examined neither the universe of policy issues elsewhere addressed in the EIS, nor the subset of those issues amenable to economic analysis or comment. Hence, the reader is referred other sections of the EIS for discussion of the effects of environmental wasteloadings and fish disease; consequences for sport and commercial fishing, marine recreation; and economic effects of public perception concerning environmental quality. An article by James A Crutchfield (Appendix L) provides an overview of the Washington salmon farming issue from an economic as well as policy perspective.

2. INPUT-OUTPUT ANALYSIS (Sections II, III, IV)

Regional input-output analysis was conducted according to theoretical principles articulated by Harry Richardson (Input- Output Analysis and Regional Economics,1972) and empirically implemented in the US Forest Service Implant System. Both these works are cited in the appendix and are generally familiar to practitioners of regional economics in the Pacific Northwest. Results were expressed in terms of gross revenues (in total and by sector), household incomes, and employment. Independent estimates were provided for Washington State and each examined county.

One comment alluded to the need for independent replication of these results. Crutchfield provides a partial basis for comparison. Crutchfield reported 7 - 10 direct employees for a 500,000-pound facility, or 14 - 20 direct employees per million pounds of production. The representative (one million pounds sold at \$5/lb) fish farm used to calculated input-output results for this appendix assumed 20 fish farming employees. Additionally, the representative facility assumed 8 employees in an associated hatchery, and 5 administrative employees for the managing firm. It is unknown whether Crutchfield included either of these components in his estimate. Crutchfield also estimated that between 140 and 200 full-time jobs would directly or indirectly result from a 5 million pound industry selling its product at \$4/lb. The reported low range estimate of 257 jobs best corresponds to Crutchfield's conclusions, by eliminating \$1/lb of net profit from the regional income account.

Responses to specific comments on input-output analysis are as follows.

1. Use of constant ratios (expenditures per dollar of revenue, etc) is standard procedure in the input-output literature, as well as being reasonable in the current situation where impacts are small relative to the magnitude of effected state and county economies.

2. Independent county models do exist, as discussed above, those being derived from the implant system.

3. State impacts were separately calculated from an independent state model, not aggregated from county results.

4. The local economic impacts of import substitution (replacing imports with locally produced fish) are essentially the same as for export of the same volume and value of product.

5. Whether hatchery location, and thus employment, occurs in the same county as the fish farm will vary in the individual case, with effects on county but not state results. While collocation was assumed in this assessment of overall industry development, case specific information should be introduced in the evaluation of specific sites. The same comment pertains to case specific variations from the representative facility in terms of production volume and/or facility mix (hatchery, farm, administrative unit)

3. FISCAL IMPACTS (Section V)

The analysis of fiscal impacts relied on the results of input-output analysis and published data on five categories of state revenue and three categories of state expenditure. For each category, fiscal factors were calculated that represented the relationship between state revenues and costs on the one hand, and input-output results (output, income or employment) on the other. Multiplication of fiscal factors by these input-output results produced the reported state fiscal results. Local government fiscal impacts, as well as site specific salmon farming costs, were too diverse and variable to permit similar estimation.

The conclusion was ambiguous. That is, depending on the fiscal factors used, and the input-output results to which they were applied, the Washington State government came out ahead or behind on its own fiscal account.

Concerning lack of emphasis on the fiscal analysis that was done, the executive summary reflects the ambiguous conclusion on cost account as follows:

> "These economic impact results provided the basis for estimates of state fiscal (revenue and expenditure) consequences. Depending on the economic impact values used and the method of relating economic impact to fiscal consequences, salmon farming would [annually] contribute $.36 - $2.26 million to state revenues and $1.08 - $1.48 to state expenditures."

A reading of this paragraph should adequately alert the reader to the reports conclusion that, depending on method of calculation, the state government account comes out either ahead or behind.

4. PROPERTY VALUE (Section VI)

DATA: Primary data on waterfront property was collected from county assessors, real estate offices, and multiple listing services. There were 335 listings in total and at least 41 from each county. Descriptive summary tables indicated the range of variation in front footage value between counties and property classifications (high/low bank, degree of development). That data is useful only for its intended purpose and <u>should not</u> be regarded as a general purpose data base for other purposes.

One commentor found Skagit County values different from her experience. I would need to examine both sets of data to evaluate this difference.

STATISTICS: A multiple regression equation was estimated in order to isolate the effects of known variables (county, bank type, degree of development) from residual variance. The first step in determining impacts on property values was to assign all residual variance to aesthetic quality. This procedure maximized salmon farming impacts, relative to any apportionment of residual variance between aesthetic and other value determining factors.

This simple statistical procedure for producing high range results was adopted over the more sophisticated hedonic pricing approach. In other environmental resource evaluation applications (such as sport fishery evaluation) hedonic pricing is used to directly determine resource value impacts attributable to resource characteristics. An example would be the use of angler success rates as a partial determinate of total angler day values. Available financial resources and data fell far short of that required by the hedonic pricing approach.

INTERPRETATION: The only direct information on the actual effect of salmon farms on property values was a cited appraisers report (Appendix K) which concluded that "floating net pens have no effect on upland property values in the areas studied [Peal Passage, Mason County, and Rich Passage Kitsap County]." Assumed losses were nevertheless included, as discussed below.

5. BENEFIT-COST ANALYSIS (Section VII)

Benefit-cost analysis was performed in terms of statewide annual gains and losses. These were derived from the results of the foregoing estimation procedure by application of factors reported in Table 7.2. One of these adjustments factors was the 8 % real interest rate (financial rate less inflation) used to convert the asset value of waterfront property to annual terms.

Salmon farming impacts on these asset values were included as costs, in spite of the above assertion of no discernable effect. This was accomplished by introducing into the benefit-cost analysis two additional factors reflecting the assumption that a defined quality index would decline from 10 to 20 percent over 5 to 10 miles of shoreline per site. This procedure was adopted to allow readers prepared to assume adverse impact to readily examine the economic implications of their assumptions. Considerable emphasis was given to the fact that such reader provided assumptions were necessary to give meaning to this procedure.

One commentor suggested that a better alternative to this quantitative approach would have been to rely on qualitative judgment of all identified impacts. The main body of the EIS, to which this appendix is supplementary, should provide the basis for such judgement.

APPENDIX F

PERMITS THAT MAY BE REQUIRED FOR AQUACULTURE PROJECTS

Permits which may be required for an aquaculture project.

Federal Permits	Issuing Agency
Section 10 Permit	Army Corps of Engineers
Navigational Markings	U.S. Coast Guard
Marine Mammal Protection Act Exemption	National Marine Fisheries Service
State Permits	
Aquatic Land Lease	Department of Natural Resources
Hydraulic Project Approval	Department of Fisheries or Wildlife
Statement of Consistency with Coastal Zone Management Act	Department of Ecology
Water Quality Certification	Department of Ecology
Water Quality Standards Modification	Department of Ecology
National Pollutant Discharge Elimination (NPDES) Permit	Department of Ecology
Aquacultural Identification of Private Sector Products	Department of Agriculture
Registration of Aquatic Farmers	Department of Fisheries
Fish Disease Control	Department of Fisheries
Shellfish Certification	Department of Health
Finfish Import/Transfer	Department of Fisheries
Local Permits	
Shoreline Substantial Development	County or City

APPENDIX G

VIRAL HEMORRHAGIC SEPTICEMIA

Viral hemorrhagic septicemia (VHS), also known in Europe as Egtved disease (named after a town in Denmark where the disease was first recognized), is an acute to chronic disease, principally of rainbow trout, caused by a virus of the same name; i.e., VHSV. There is much concern in Washington State and North America because of the isolation of this virus here in 1988. Some people speculated that VHSV was introduced into Washington as a result of aquaculture and sea-water net-pen activity with Atlantic salmon. The scientific community has found no evidence to support this speculation. This paper presents information about VHSV, how and where it was found in North America and some suggestions as to the mode of introduction and potential impact.

BACKGROUND AND BIOLOGY OF VHSV

VHS is caused by a rhabdovirus. It occurs in continental Europe in the countries with intensive salmonid culture to include Denmark, France, Germany, and Italy. Observations of VHS have also been made in Poland, Czechoslovakia and is suspected to be in Russia (Wolf 1988). The disease was observed in a trout farm in Norway in the mid-1960s where rainbow trout had been imported from Denmark. The disease was eradicated from the farm and has not reappeared in Norway (Hastein 1968 and personal communication). VHS has never has observed in Finland or Great Britain.

The virus is very similar in its characteristics to a virus which does occur in North America -infectious hematopoietic necrosis virus (IHNV). They both cause acute to chronic mortality in rainbow trout with fry being the most seriously affected and having the highest mortality. Species shown to be naturally infected by VHSV include rainbow trout, brook trout, whitefish, grayling, and pike (Wolf, 1988; Rasmussen, 1965). While researchers have been able to induce VHS in Atlantic salmon by an unnatural challenge (interperitoneal injections) they have been unable to induce disease by a water-borne challenge in the laboratory (Rasmussen 1965; deKinkelin and Castric 1982). In one challenge, deKinkelin was able to demonstrate in the laboratory the presence of VHSV in Atlantic salmon fry after exposure; however, the fish did not become diseased nor were the Atlantics able to subsequently shed the virus and infect sentinel rainbow trout in the same tank (deKinkelin and Castric 1982). VHSV has never reported to have been found in hatchery or wild Atlantic salmon stocks even though extensive surveys and certifications have been performed. Coho and chinook salmon have both been demonstrated to be resistant to VHSV infection by both a water-borne challenge and interperitoneal injections (deKinkelin et al. 1974; Ord 1976).

The manner in which viruses are isolated and broodstock are tested is also of interest. For salmon and trout broodstocks in Washington or stocks outside Washington wishing to enter the state, rigorous testing procedures are required. Samples of gonadal fluids, as well as a kidney and spleen are taken from a statistically significant portion of the population. The samples are assayed in a living tissue culture system using standard methods (Amos 1985). Personnel and laboratories conducting these certifications are inspected and approved by Washington Department of Fisheries personnel. Our staff and the Olympia Fish Health Center (USFWS) were using these standard techniques when they isolated VHSV in Washington state.

The known method by which VHSV is transmitted from fish to fish is via the water or by ingesting infected material. This method of pathogen transmission is known as horizontal transmission. This process also takes place with IHNV. Another method by which virus may be transmitted is via the eggs or sex products. During spawning of susceptible species (rainbow trout) VHSV and IHNV have been found to be present with the sex products. When pathogens are transmitted from the parents to the offspring via the eggs or sperm, this is referred to as vertical transmission. True vertical transmission implies transmission of the pathogen within the eggs. This has never been demonstrated to occur. We have observed a phenomenon with IHNV which is more appropriately described as "egg-associated" virus transmission in which either through surface contamination or possibly within the egg virus subsequently causes infection. These observations were made on eggs incubated in well water so the assumption was made that the known infected parents were the source of the virus which infected the eggs. The distinction between transmission on the egg or within the egg, is important as the surface of the egg can be exposed to disinfectant while the inside of the egg cannot be disinfected. Even though egg-associated transmission of IHNV has been observed, it is not a common event and has been observed only in sockeye salmon and rainbow trout. VHSV has never been observed as being egg-transmitted.

ISOLATION IN WASHINGTON STATE

Routine broodstock screening for virus in chinook salmon at Glenwood Springs (Orcas Island) and coho salmon at the Makah National Fish Hatchery (Neah Bay) yielded replicating agents which were identified to be VHSV. This was a remarkable find in that VHSV had never been found previously in North America. Furthermore, contrary to the existing literature, VHSV had never been described in coho or chinook. As was previously stated, researchers in Europe were unable to induce infections in chinook or coho.

As a result of those isolations, an action plan was put into effect by the Washington Department of Fisheries. All fish and eggs at the affected hatcheries were destroyed and disposed of in a sanitary manner. The facilities were completely disinfected. Our intent was to eradicate VHSV. This was consistent with state and federal regulations and policies. Subsequent surveys and live box testing of the watersheds failed to find virus. Testing of fish in adjacent watersheds and also of feral fishes in the marine area failed to produce VHS virus. Because of the concern that commercial net pens might have been the source of the virus they were examined also. Consistent with ongoing testing and viral certification of commercial broodstocks in Washington, they were all negative for virus. In addition to testing, a thorough review was made of introductions of fish from Europe. We were unable to find documentation of introduction of fish from VHSV endemic area into Washington. Since 1985 when commercial imports of fish came under the Washington Department of Fisheries' jurisdiction, very few imports of eggs have come to the state. These eggs have come from Norway and Finland, where VHSV is not known to exist. Furthermore, the broodstock which provided the eggs were carefully scrutinized. Records of the Washington Department of Fisheries and those maintained by customs inspectors and USFWS inspectors are in agreement.

Virus inspections of 100% of the adult salmon returning to Glenwood Springs and the Makah NFH as well as extensive screening of public and private salmon stocks failed to isolate VHSV in 1989 broodstock with one exception to date (1/5/90). Coho salmon adults returning to spawn to the Lummi Island Sea Ponds (saltwater rearing ponds operated by the Lummi Tribe) were shown to be infected with VHSV. Only one pool of samples was demonstrated to contain virus which likely represents only one but not more than five individuals. As in 1988, this isolation was made from adults immediately leaving the straits which again suggests that infections took place in the Pacific Ocean/ Puget Sound. Though WDF efforts to eradicate this virus from the Glenwood and Makah facilities appears to have been successful, the source or opportunity for infection seems to persist.

Yet to be resolved is the source or the reservoir for infection of VHSV in Washington state. All the hatcheries are in proximity to the Straits of Juan de Fuca and all hatcheries are very close to sea water. The data suggests that the adult salmon were infected as they entered the hatcheries and were, therefore, infected in saltwater. Potential sources of infection could be: (1) unknown carrier fish in the ocean, which are circumpolar in nature which came in contact with or were ingested by the salmon; (2) introduction of carrier fish or animals in bilge water discharged off the Washington Coast; (3) a condition which has existed in our salmon stocks for many years, but below detection level; and (4) the legal or illegal introduction of fish or fish products into Washington which, in turn, established a reservoir in some carrier animal in saltwater.

Many questions remain to be answered such as: How is our VHSV similar/different to European strains? Does our isolate cause disease and if so, in what species? What is the reservoir for the virus? Research to be conducted in 1990 will address these questions.

SUMMARY

- VHSV was reported for the first time in North America in 1989 in coho and chinook salmon adults in Washington state in 1988 broodstock.
- VHSV isolated in adult coho salmon in 1989 broodstock returning to Lummi Bay Ponds, a new site.
- No disease or mortality was associated with the VHSV isolations in Washington state.
- Extensive surveys failed to show the source of the infection.
- Infection of the adult salmon appears to have occurred in saltwater.
- No VHSV was found in fish from commercial net-pens.
- VHSV has never been reported to occur in Atlantic salmon.

- VHSV has never been demonstrated to be transmitted via the eggs.
- No evidence was found which indicated that import of eggs by public, private, or Indian tribal entities was responsible for introducing VHSV.

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APPENDIX H

NORWEGIAN AND BRITISH COLUMBIA INFORMATION

ICES 1988 PAPER C.M. 1988/F:11

LENKA - A NATION-WIDE ANALYSIS OF THE SUITABILITY OF THE NORWEGIAN COAST AND WATERCOURSES FOR AQUACULTURE. A COASTAL ZONE MANAGEMENT PROGRAM

by

Tom N. Pedersen[1], Jan Aure[3], Bjørn Berthelsen[4], Siri Elvestad[4], Arne S. Ervik[1] and Håkon Kryvi[2].

1)
Institute of Marine Research
Division of Aquaculture
C. Sundtsgt. 37
N - 5004 Bergen

2)
County Environmental
Protection Department
Walckendorffsgt. 7
N - 5000 Bergen

3)
Institute of Marine Research
Box 1870 - Nordnes
N 5034 Bergen

4)
Ministry of Environment
Department of Natural Resources
P.b. 8013 Dep.
0030 Oslo 1

ABSTRACT

A coastal zone management program called LENKA was started in 1987 and is to be terminated in 1989. The aim is to make an efficient and standardized tool for coastal zone planning, which, pertaining to law, is the responsibility of the county and municipality. The program aims to be beneficial for both the environment and for the fish farmers. Consideration is taken to all important existing utilization and judicial aspects connected to the Norwegian coastal waters. This is done by a systematic collection of all available data, systemized in such a way that they are available for future planning.

A model for the evaluation of the holding capacity primarily for cage culture based on both oceanographical and topographical criteria is put forth. The coast is divided into three categories of recipient based on topography. A central clue in this model is the evaluation of indices for the quantity of aquacultural activities (measured as organic deposits into the recipient) one may have per square kilometer in differently categorized recipients.

INTRODUCTION

Aquaculture in Norway is based on salmon and rainbow trout. The growth of the industry has been rapid, with an almost two fold production increase every second year. The total production this year is expected to be about 80 000 metric tonnes, but the continued growth is expected to be slower. Up to now, the limitation has mainly been on the number of smolts available, this situation is now reversed, partly due to the liberation of smolt production permits.

There is a keen interest in the potential of cultivating marine species, especially halibut and cod. Much effort is put into solving the problems of the rearing of juveniles, and this seems to be solved for cod and turbot. Other species of interest are arctic char, wolf fish, eel and lump fish. Some shellfish are being cultured, mostly blue mussels and oysters, in addition to experiments on scallops. Also and some experiments on ranching of lobster is being performed.

The main asset in Norway for this rapid growth in the aquaculture industry has been the access to vast amounts of water of good quality, both fresh water and salt water. Space and water quality was not a limiting factor to begin with, but is becoming so now. So far, the only measurement available in the assessment of holding capacity, is the amounts of organic waste from mariculture.

There is a need for a planning tool, consisting of directions and knowledge, to aid the development in such a way so that a high productivity is maintained at the same time as conflicts with fisheries, conservation interests, leisure activities and other utilization is kept low. The tool will have to be standardized and rational.

Both county and local municipality have the need for a plan on how to utilize the marine resources. The county plan is a guiding one, the judicial binding is not persistent before there exists a plan approved of by the local municipality.

This paper, written by the expert group on marine environment, presents the biological and oceanographical aspects of the project.

This is a description of an ongoing project where the guidelines are not yet completed. As we believe that there is a considerable interest in these matters, we find it appropriate to give some information on the project at its present state.

THE PROJECT

The project is a cooperation of three ministries, the Ministry of Fisheries, the Ministry of Environment and the Ministry of Local Government and Labour. Its name **LENKA** is a Norwegian abbreviation meaning: A Nation-wide Analysis of the Suitability of the Norwegian Coast and Watercourses for Aquaculture.

The project aims to :

* To contribute to a continued positive development and growth of the aquaculture industry with minimal conflicts with other utilizational and conservational interests.

* To contribute to the county and municipality planning in the coastal areas and watercourses.

* To contribute to the siting process of aquacultural activities.

The project is a planning tool, and not a plan in itself. Further, it does not aim at the site as a working level, but handles larger areas as the base unit, later referred to as LENKA zones.

Project organization :

Figure 1 gives a schematic picture of the project organization.

The development of the working methods is done by the three expert groups and the secretariat at the Ministry of Environment, while the gathering of data, map work etc. is to be performed by the county project organizations. The three expert groups are placed at the institutions with the relevant competence. The group working with watercourses

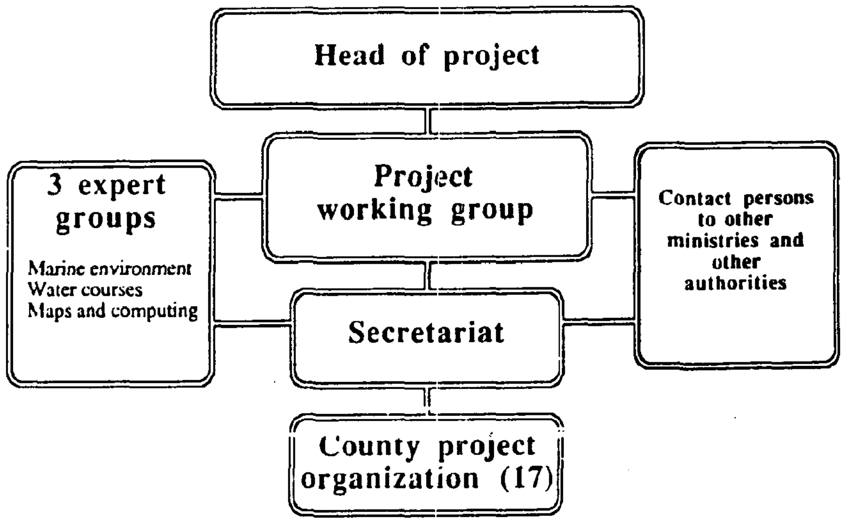

Figure 1: The LENKA - project organization. The head of the project consists of the Secretaries General from the Ministries of Fisheries and Environment. The project Working group has 3 members from the Ministry of Fisheries, 3 from the Ministry of Environment and 1 member from the Ministry of Local Government and Labour. The Secretariat is placed at the Ministry of Environment.

is placed at the Directorate for Nature Management, Trondheim. The group working with maps and computing is placed at the Norwegian Hydrographic Service, Stavanger. The two latter's part of the project will not be presented in this paper.

The group working with the aspects concerning the marine environment is placed at the Institute of Marine Research, Bergen. In addition, the group also has members from other institutions, such as the County Environmental Protection Department, the Ministry of Environment and Nordland College, Bodø.

The project has a total cost of 40 million NOK spread over three years.

THE MAIN WORKING PROCEDURE

The main working procedure of the project is shown in figure 2 (next page).

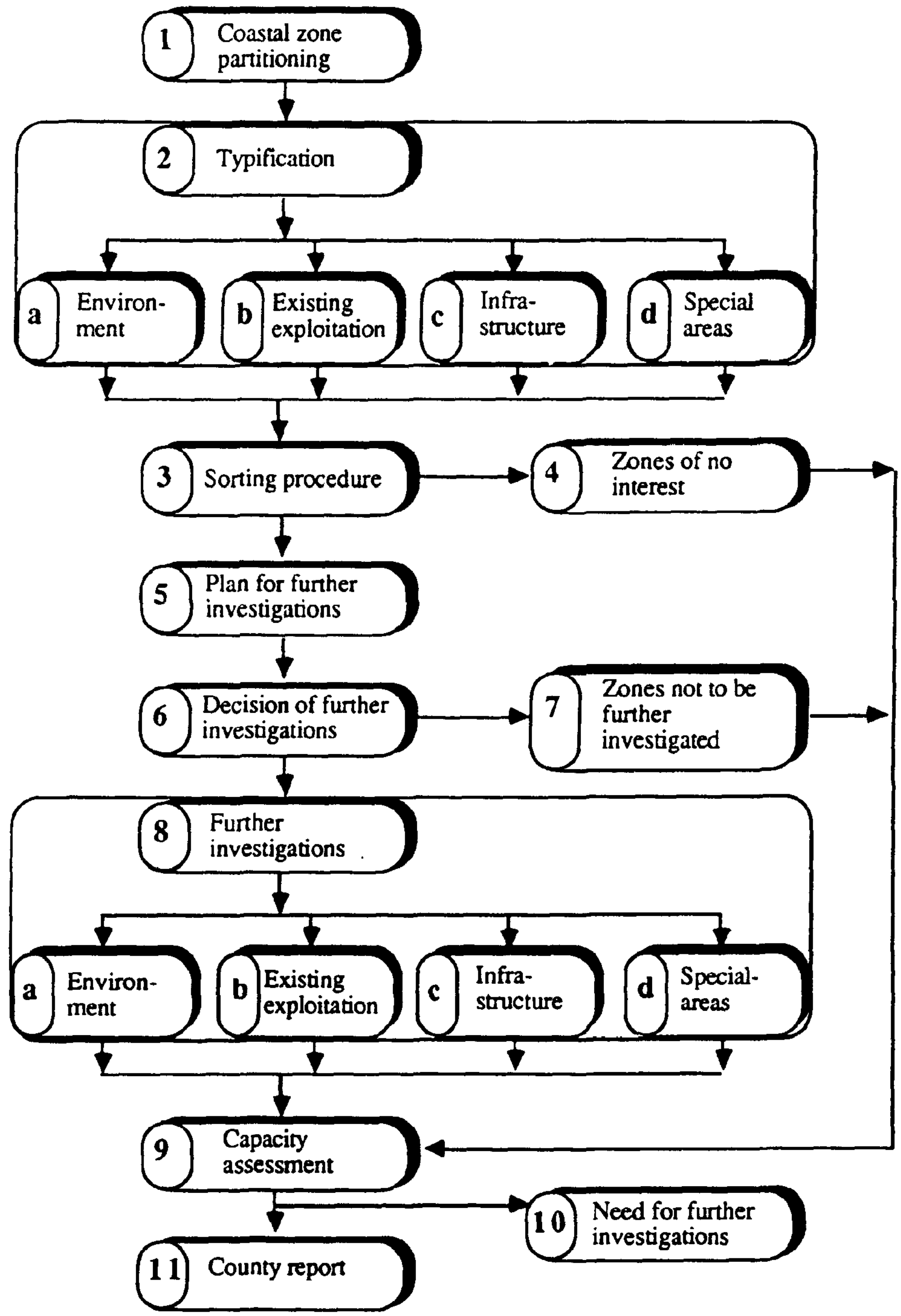

Figure 2 : The main working procedure of the LENKA - project.

ZONE PARTITIONING

In order to be able to deal with our 57 000 km long coast line in portions of manageable size, a partitioning is necessary. The principle of the partitioning is that each major water volume should be handled separately. Roughly, the coastal zone is divided into smaller areas (LENKA-zones) each being either an archipelago, a fjord, a large sound or an open fjord basin. The smaller areas will reflect the water bodies capacity to handle the organic loadings received from both aquaculture and other sources.

In order to separate the water volumes, the borders should to a large extent as possible follow land. An example of how this looks like is shown in appendix 1, where the partitioning of County Hordaland (where Bergen is situated) is shown.

TYPIFICATION

Typification of zones is a registration of the environmental properties of the area. In this project the aim is to collect and systemize the data that already exist. For some parameters the data will be scarce. This is taken into consideration, and follows the description of the area. The compiled information will be transferred to maps, the result being a visualized presentation of the environmental properties of the marine environment. Similarly, this is done for the other three main groups of parameters, Existing exploitation, Infrastructure and Special areas.

The following parameters and their significance were used for the typification of the zones. These are the major environmental parameters that have influence on the utilization of the coastal areas for aquaculture. We would like to note that we do not consider any technological devise that frees the farming installment from the marine environment surrounding it. This is mere a question of economy, and will not be considered in this project.

ENVIRONMENTAL PARAMETERS USED FOR TYPIFICATION OF ZONES :

Pollution :

The point in this connection is that the contamination of the environment effects the health or the marketability of the fish raised in these waters. Also, we distinguish between two categories of pollution; toxins as one kind and organic loadings as another. Most important are the massive outlets from industry and agriculture. Some areas are severely polluted by heavy metals and toxins from specialized industries. In addition there are several smaller sources of various kinds of pollution with a more or less restricted effect on the marine environment.

Temperature :

When considering temperature conditions in Norwegian waters, low temperatures is the main hindrance of aquacultural activities, though there are some problems with too high summer temperatures in some parts of the country. Of interest are the extreme temperatures occurring within a time span of 5 - 6 years (our definition of frequent). Areas reckoned as unsuitable for aquaculture have regular long periods, that is 6 weeks or more, with temperatures below zero centigrade. Measurements ought to be taken at depths of 2 to 5 metres.

Ice cover :

Of interest are the areas covered with ice at least every five years.

Exposure :

The actual parameter here is wave height, though current velocity also is part of the exposure problem. Current in itself only occurs as a problem locally, but infers on the wave height. Suitable areas for cage culture is where the wave height does not exceed 2 m. For wind to generate such a wave height, a stretch of 10 km open water is needed. Here we would like to add that the general development of the aquaculture industry in Norway has been towards more robust cage constructions, with cage systems being able to stand up to wave heights of up to both two and three metres.

Depth conditions :

The depth required under the cages is dependent on the current velocity to ensure that the wastes from the farm is spread. Also this is a way to avoid possible eruptions of hydrogen sulfide gas from the sediment that often accumulates under the cages to reach the fish in the cages. As a general rule we have set 20 m depth to be a minimum criterion for cage culture, with the possibility of adjustments to current velocity.

Basins :

A basin is a water volume restricted from the outer lying larger water masses by a threshold. A basin is defined as where the depth of the basin is at least 10 m deeper than the threshold. This water volume is sensitive to organic loadings, causing a possible disturbance of the oxygen balance. All thresholds shallower than 50 m have been registered.

Salinity :

The influence of freshwater causes several problems for the fish farms. A layer of brackish water on top of the salt water resulting in a strict stratification, may cause severe fluctuations in salinity and also fluctuations in temperature. As a limit for when the influence of fresh water becomes a problem, we have put the salinity measurement to 25 ppt.

Other main groups of parameters :

Under the heading of existing exploitation we list the followings parameters :

- effects on settlement patterns
- open air recreation life
- port development
- fisheries
- shipping traffic
- other factors .

Further, there is a separate heading called infrastructure, dealing with the particular requirements which should be met for an aquaculture enterprise to succeed. Main parameters are :

- road development
- distribution of manufactured feed
- processing facilities
- health service and guiding service
- offal disposal systems.

The last heading is special areas, conditions that might conflict with further development of aquacultural activities. Examples here are :

- spawning grounds for important fisheries species
- reserves for coastal birds and marine mammals
- others.

A MODEL FOR CAPACITY ASSESSMENT

Some imperative reservations :

With capacity we mean holding capacity, which is : the maximum production limited by a non trophic resource. Or put in a simpler way, what quantity of aquacultural activity is possible in an area without there being damage caused to the environment. This is measured as deterioration due to organic overloading causing eutrophication, oxygen depletion a.s.o..

This method of capacity assessment of LENKA zones is based on the emphasis of two main considerations :

1) the environmental impact from mariculture
2) the marine environment's impact on the cultured organism.

It is by no means possible to give exact values on what loadings from mariculture are acceptable, that is, how much organic waste from mariculture is possible without any negative influence on the surrounding environment. Some general recommendations are given in the State Pollution Control Act, the entire aspects are being dealt with by the Ministry of Environment and the State Pollution Control Authority. The total environmental impact from fish farms will manifest themselves several years after the farm has started production.

To be able to assess any capacity for aquaculture, one has to take into consideration the contribution from all major sources of organic loadings.

Elements of the capacity assessment :

Many parameters affect the capacity assessment. Not only the above mentioned parameters are of importance. The LENKA - project takes into consideration the elements shown in **figure 3**, and the working procedure is shown in **figure 4**. As is shown, there are two main aspect in the

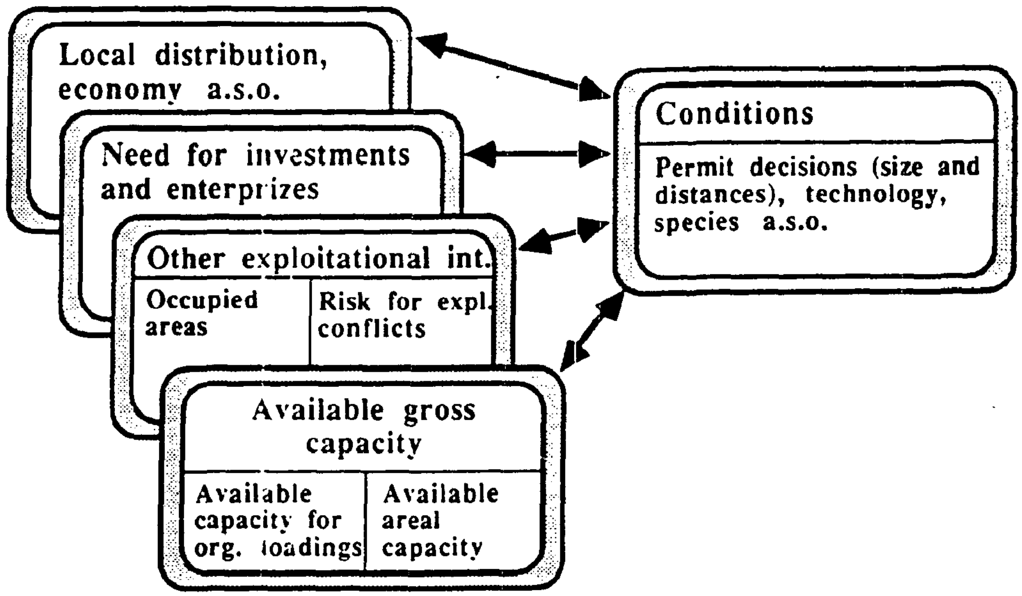

Figure 3 : Elements of the capacity assessment.

capacity assessment. One aspect is the evaluation of the capacity for organic loadings in water body (LENKA zone). This is done by treating the zones properties as a recipient for organic loadings. The other aspect is based on space. The water body, or more precise, parts of it, is occupied by other activities as mentioned earlier. There exists a net area available to aquacultural activities. One of these will set the limit to aquacultural activities.

In our capacity assessment we have based the calculations on organic loadings, and thereby neglected limitations set by factors such as risk for spreading of diseases, use of chemicals and therapeutica etc. There exists a veterinary regulation on distance between farms, this is set to 1 km. Criteria as such may be altered as the knowledge increases.

The recipient capacity :

Classification of coastal areas within the zones :
Classification is based on topography. This again reflects the water exchange regime in the area, as well as being an indicator of the area's

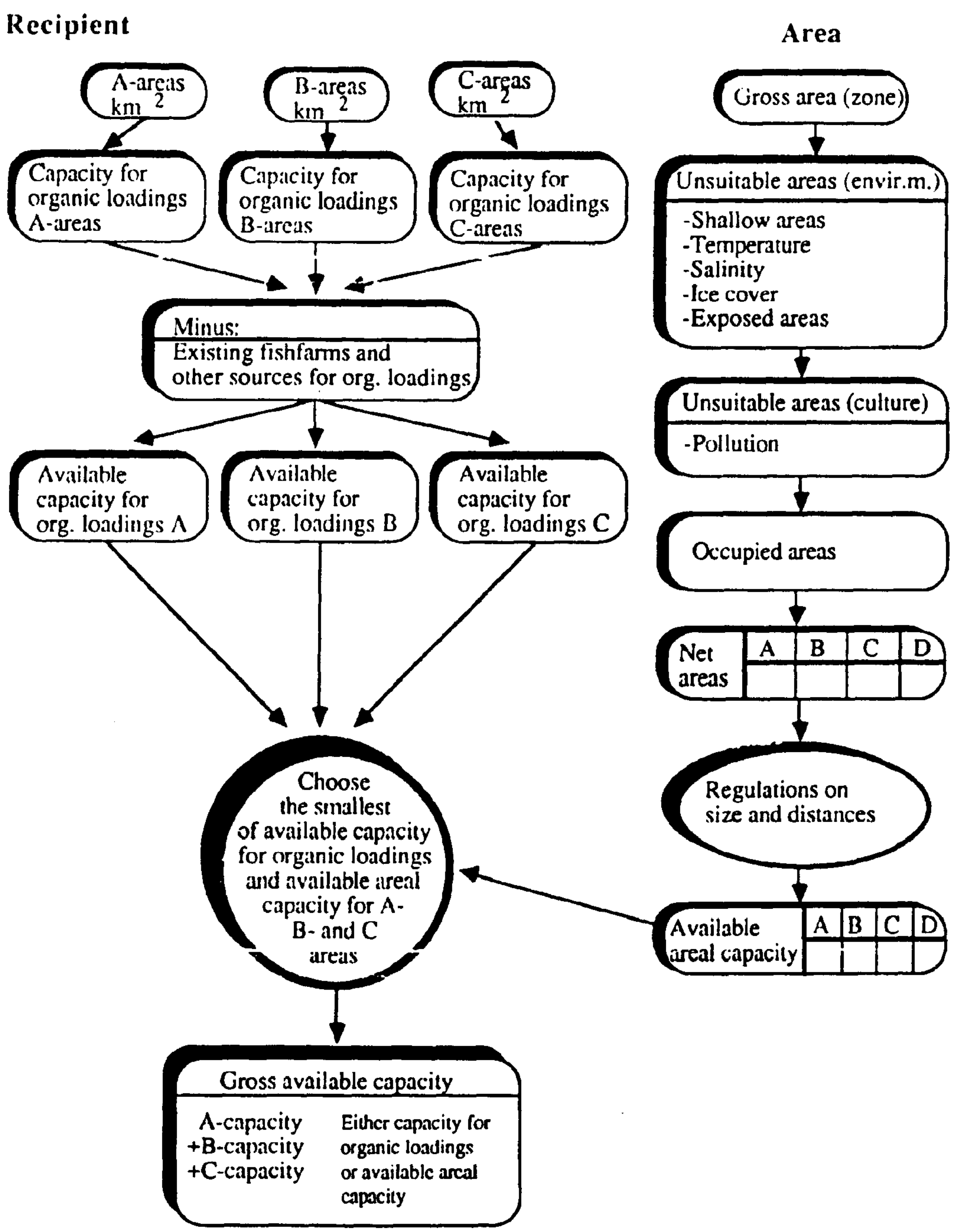

Figure 4 : Calculation of gross available capacity.

property as a recipient. An exact classification with illustrations is given in Appendix 2.

For each recipient category A, B and C there is given an index for how much aquacultural activity is recommended. This is expressed as a certain production in terms of tonnes per square kilometre. Here we would like to emphasize what care was taken before these indices were given. The procedure was as follows :

From empirical data we were able to extract the general statement on how large production one could have in a specific area without it causing damage to the environment. The effects were investigated by sediment fauna monitoring. These levels of production were converted to production per square kilometre. Again, based on facts about Norwegian fish farms, these values were converted to organic loadings, expressed as oxygen consumption, total phosphorous and total nitrogen.

As a correction factor one would have to adjust these figures for other major outlets of organic waste. At the moment we are, together with the appropriate institutions, giving a simplified method for estimating the impact on the marine recipient based on key figures ready available. The capacity is calculated in terms of organic waste, and is therefore independent on the technology being used. New technologies resulting in reduced outlets from the farms can easily be incorporated in the calculations.

Further, when capacity is expressed as production as tonnes per km^2, this sets restriction to the size of single farms and to the total activity in larger areas. The values are not decided yet, but the capacity will be expressed as the following :

A - categorized areas : a maximum production per (4x4) km^2, but not more than a lesser specifies quantity at a single site. A site is defined as occupying a minimum of 1 km^2. Where the recipient conditions are particularly good, and the number of sites available is restricted, one may exceed these recommendations.

B - categorized areas : similarly as above, there is given a maximum production per (4x4) km^2, and a lesser one at a single site.

The capacity per (4x4) km^2 will be in the magnitude within one thousand metric tonnes for both A- and B - categorized areas.

C - categorized areas : these areas are basins and silled fjords, and special care should be taken in such areas. Aure & Stigebrandt have developed a model for the calculation of oxygen consumption in silled fjords (Aure and Stigebrandt 1988, Stigebrandt and Aure 1988), and this can in turn be used as a method for the calculation of capacity in terms of organic loadings. The calculations can be done given the hydrographic data and topographical maps.

Where there is oxygen depletion in the basin water, aquacultural activities are not recommended in silled fjords. In basins within archipelagos one should ensure that the water in the deeper layers of the basin does not suffer from oxygen depletion. This means that in an area categorized as a C grade recipient, no aquacultural activities are recommended before one has sufficient data so that damage to the environment is avoided.

This method is dependent on a monitoring and control scheme, and this will have to be a perpetual process. In this way there is the possibility of adjusting the proposed capacity assessment, and at there is possibility of keeping an eye on what is happening to the environment. The monitoring and control schemes are not established.

The areal capacity

Unsuitable areas :
Each LENKA - zone has a gross area divided into A, B and C type recipients. Parts of these areas may be unsuitable for aquaculture, that is, unsuitable for cage culture for as it is practiced in Norway. Unsuitable areas consist of environmentally unfavorable areas from both natural conditions and as a result of man's activities. The last case is mainly pollution, and in this case pollution of toxicants that directly affect the fish health and marketability.

The environmental parameters taken into account are : Shallow areas, cold water, low salinity, ice cover and exposed areas.
In addition to these unsuitable areas there are certain areas that are

bound up by other activities. Such areas are :

- area already occupied by existing aquacultural activities
- nature reserves and animal protection areas (both birds and sea mammals)
- *security zones for salmonid fish*

In addition areas are occupied for military purposes and for ship navigation.

Having subtracted all these areas, one is left with a net areal capacity which can be compared with the recipient capacity. The smallest of these will set the limit. All these calculations will be performed by computers as all the information is to be tabulated ready for a for this purpose constructed work sheet.

Finally, we would like to mention the work initiated to eliminate the interactions between wild stocks of salmon and trout and farmed fish. The possibility of affecting the genetics and spreading of diseases has been much debated. There is now suggested temporary protection zones for salmonids, with a supporting research program. Further information on this is available on request.

In addition to the names and addresses in the author list, there are a few more names to add. If anybody should have any particular interests, the following persons may be contacted :

MAPS AND COMPUTING :

Asbjørn Hiksdal
Norwegian Hydrographic Service
P.b. 60
N - 4001 Stavanger

WATERCOURSES :

Øystein Albu
Directorate of Nature Management
Tungasletta 2
N - 7047 Trondheim

PROTECTION ZONES FOR SALMONIDS :

Bjørn Lindgren
Ministry of Environment
Department of Natural Resources
P.b. 8013 Dep.
0030 Oslo 1

REFERENCES

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Appendix 1 :

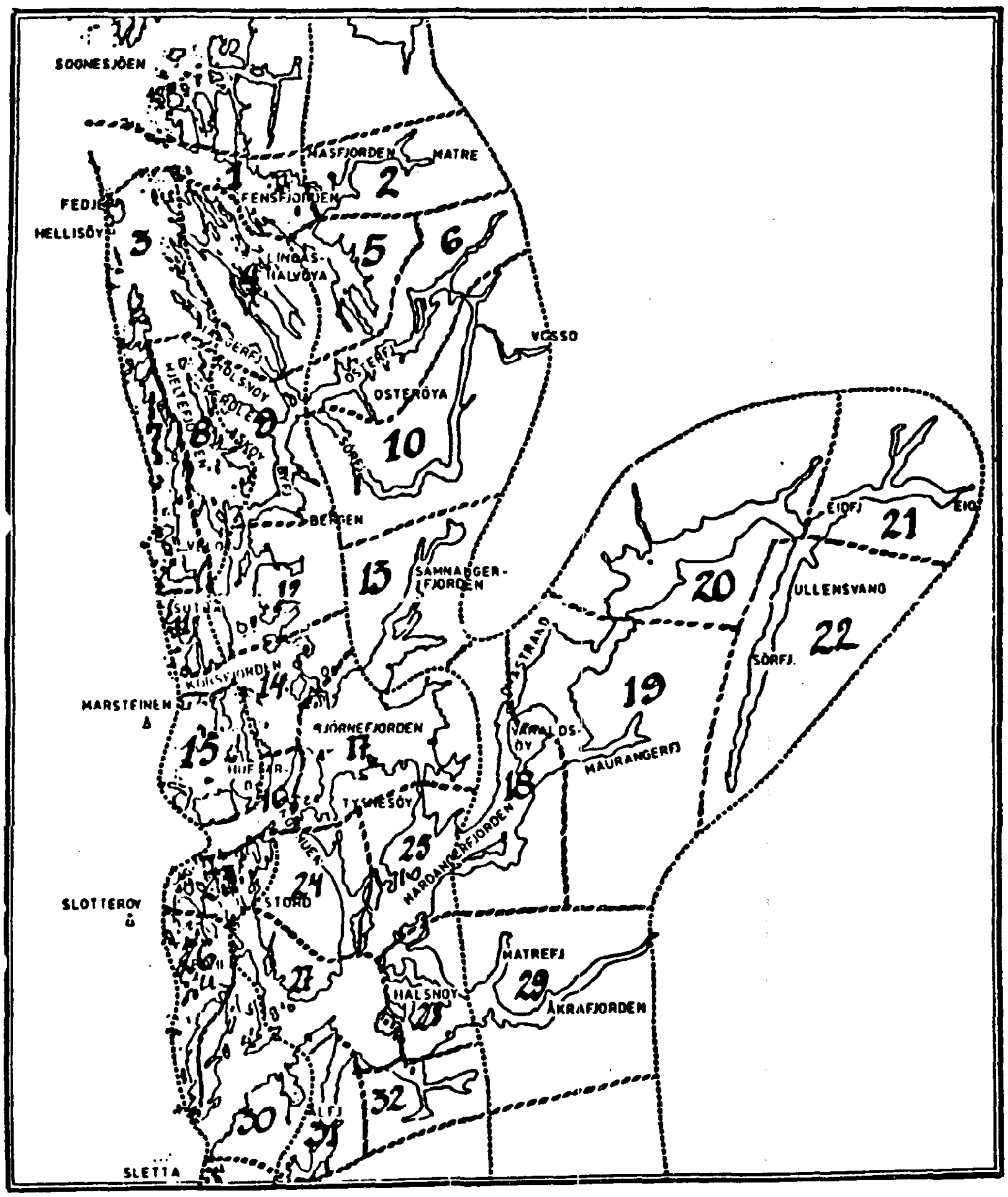

Figure 5 : **Example of zone partitioning for the County Hordaland, Western Norway.**

Appendix 2 :

Division of the coastal zone into smaller areas based on assumed water exchange rate caused by topography.

A : Open coastal areas and large fjords where depth is larger than 50 m.

A_1 : Open coastal areas where depth is larger than 50 m. Size and sills are not considered.

A_2 : Large fjords where :
Length of more than 10 km, and
No presence of sills[1].

B : Other areas with good water exchange.

B_1 : Open, sill - free areas as A_1 (archipelagos) and large fjords as A_2 but where largest depth is less than 50 m.
Length above or less than 10 km.
Depth[2] is less than 50 m.
No presence of sills.

B_2 : Smaller fjords, bays and inlets where :
Length is less than 10 km.
No presence of sills.
Depth is greater than 50 m.

B_3 : Large, silled fjords[3] where :
Length is greater than 10 km.
Presence of sills.
Depth may be more than 50 m.

C : Small silled fjords an other silled areas (archipelagos) :
Length of fjord less than 10 km.
Presence of sills[4].
Depth may be more than 50 m.

Examples are shown on the sketch on the next page.

1) : A silled area is defined as an area where the inside basin is at least 10 m deeper than the sill. Sills down to 50 m are registered.

2) : Fjords are reckoned as shallower than 50 m when more than 60 % of the area fulfills this criterion.

3) : Fjords and other areas with several succeeding sills is reckoned as a "new fjord" when the succeeding sill is shallower than the preceding one.

4) : In sounds and basins within archipelagos with several sills, the deepest sill is reckoned as the main entrance to the basin.

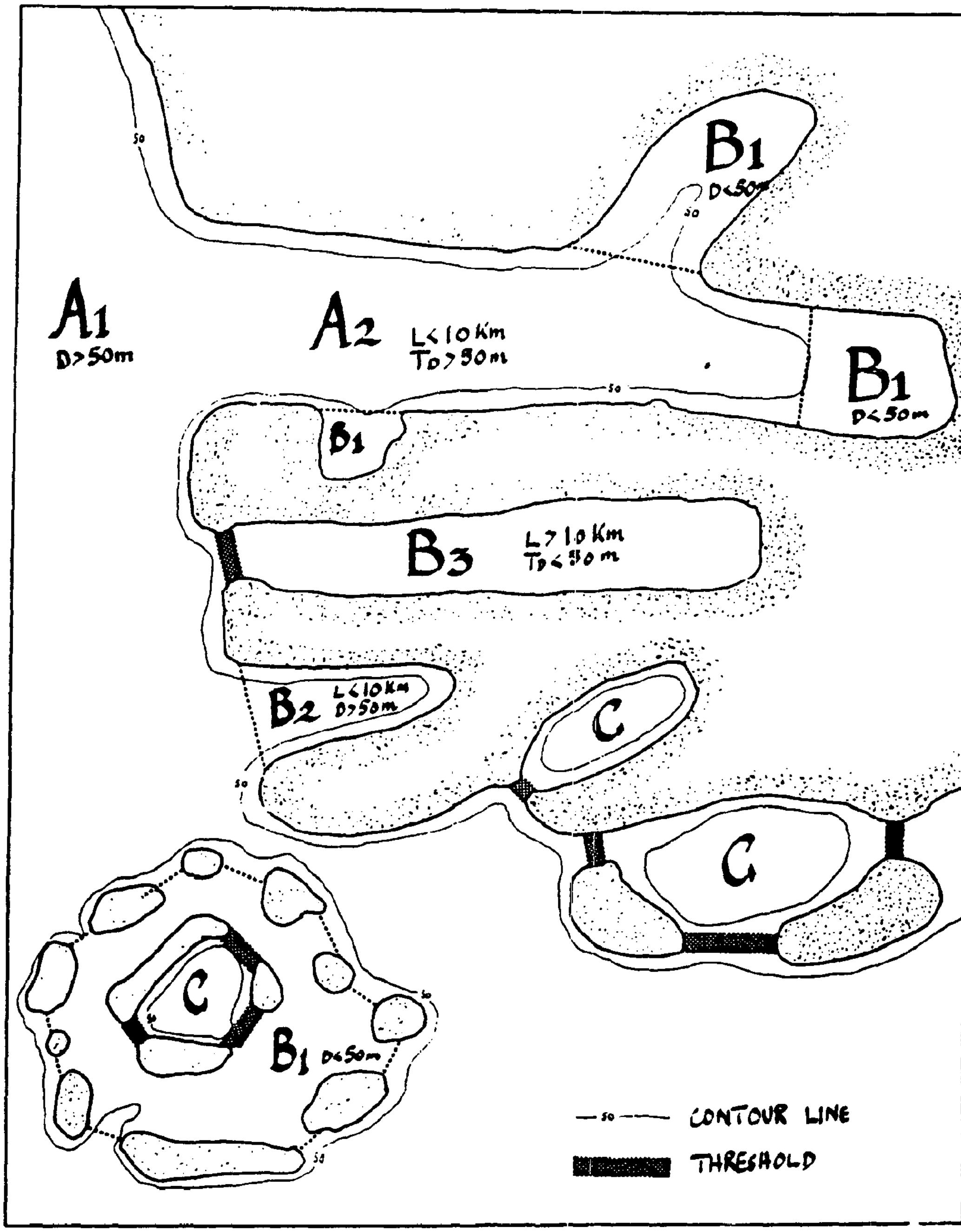

Figure 6 : Examples of division into categories A, B and C.

Legend : D = depth, L = length, T_D = threshold depth.

BRITISH COLUMBIA
AQUACULTURE LICENSING & REGULATIONS

September 27, 1989

AQUACULTURE LICENSING AND REGULATIONS - A SUMMARY

Rationale for Provincial Aquaculture Licence

A large, completely new industry that is dependent on common property resources cannot exist in a vacuum of government involvement. Appropriate government intervention is needed to protect the public interest, yet ensure that the economic benefits of the aquaculture industry accrue to British Columbia.

The size and growth rate of aquaculture has threatened other interest groups. This significant new industry needs some regulation to ensure responsible growth and development and at the same time provide a comfort factor for groups that feel threatened and would block further aquaculture development.

Aquaculture is currently administered by six different agencies in three levels of government (Appendix 1). There are two categories of approvals needed by an aquaculture operator. The first category is primarily approval to locate a facility and includes Crown land tenures, navigation compliance and zoning compliance. The second category is approval to operate a facility. The latter has been issued by the Department of Fisheries and Oceans (some marine sites) or Ministry of Environment (freshwater sites). The Ministry of Agriculture and Fisheries, as lead agency, proposes to consolidate and reduce the operational licences to one as provided for in recently signed agreements with both these agencies. Approximately 740 sites are currently authorized for aquaculture in British Columbia (Appendix 2).

Licensing Options Considered

1. Status quo.

2. No licensing by any agency.

3. Consolidated Aquaculture Operation Licence - Approved in principle by Cabinet.

   Use an aquaculture "operational" licence as a registration tool and use regulations to facilitate orderly industry development.

This option provides a balance between administrative simplicity and government intervention. There are several advantages to this approach:

1. Consolidates operations licensing within one agency, reducing the total number of government agencies directly licensing industry;

2. Establishes standard criteria for a licence and eliminates inequities in the treatment of different components of the industry that arise from multiple agency involvement;

3. Assists industry in obtaining operational financing. Licensing is a legal tool for identifying persons who may have a private property right in stock being cultivated;

4. Provides a framework to develop future controls, if necessary, to limit or restrict practices that become problematic;

5. Replaces the Federal Department of Fisheries and Oceans and the Ministry of Environment in their industry licensing role while maintaining their input to the licensing process.

6. Establishes an equitable and efficient basis to determine eligibility for and issuance of sales tax exemptions;

7. Provides a systematic means of identifying all aquaculture operators for revenue and statistical purposes; and,

8. Establishes a uniform basis for identification of bona fide aquaculturists for other regulatory purposes including:

    - transportation and transplantation for cultured plants and animals;

    - purchase of therapeutants; and,

    - purchase of surplus salmon eggs from the Federal government.

Fees will be charged to recover costs of administering the licensing system.

Fisheries Act and Draft Aquaculture Regulations

Relevant sections of the Fisheries Act and the current draft of the Aquaculture Regulations form Appendix 3.

It is important that the regulations be read in the context of the Fisheries Act R.S.B.C. upon which they are based and with which they mesh. Appendix 3 is therefore organized in two sections. The first is a compilation of those sections of the Fisheries Act relevant to aquaculture licensing, together with a commentary. Material from the Act is given in bold type, while the commentary is shown in lighter type. **This revision includes changes which came into force with the proclamation of specific sections of the Miscellaneous Statutes Amendment Act (No.2), 1987, which occurred in June 1989, and in the Miscellaneous Statutes Amendment Act (No. 2), 1989, which was passed in July and was proclaimed by Order in Council in August 1989.** The second section is the latest draft of the Aquaculture Regulations with commentary and explanatory notes. Proposed sections of the regulations are given in bold type and the commentary is in lighter type.

This draft of the regulations, and particularly the commentary, includes revisions made on the basis of comments made on earlier drafts by aquaculture commodity groups, the Department of Fisheries and Oceans, the Minister's Aquaculture Industry Advisory Council, and from discussions with Legislative Counsel, Ministry of Attorney General.

APPENDIX 1
LICENSING AQUACULTURE

	CURRENT SYSTEM	PROPOSED SYSTEM
A.	LOCATION APPROVALS	
i.	**Ministry of Crown Lands** - issues leases and licences of occupation for aquatic land	Where operations are on Crown land, aquaculture licensing will be administratively linked to the Crown land application process to minimize industry's paper burden.
ii.	**Federal Department of Transport** - issues navigation compliances for all marine and freshwater aquaculture operations where physical structures do not impede navigation	No change
iii.	**Regional Districts, Municipalities** - may control the location, size, setbacks, etc., for aquaculture operations through zoning bylaws	No change
B.	OPERATIONAL APPROVALS	
iv.	**Federal Department of Fisheries and Oceans** - licenses salmon farms in freshwater and marine locations and invertebrate species other than oysters	The federal government will withdraw from licensing aquaculture under a federal-provincial agreement recently signed.
v.	**Ministry of Environment (MOE)** - issues permits for freshwater fish farms and hatcheries	MOE will withdraw from permitting commercial aquaculture activities under the recently signed agreement, but will continue to control the holding of live fish for purposes other than aquaculture.

vi.	**Ministry of Agriculture and Fisheries**	
	- registers shellfish growers on Crown land	Aquaculture licences will replace this form of registration.
	- issues Bona Fide Aquaculturists Certificates for tax exemption	The aquaculture licence will become a prerequisite for these certificates.
vii.	**No agency**	New aquaculture licences will apply to all operations of the industry, including those operations that currently are not responsible to any agency.
	- some facilities, such as shellfish hatcheries and some operations on private land, fall outside all existing jurisdictions	

APPENDIX 2
BREAKDOWN OF AQUACULTURE SITES BY TYPE AND LOCATION OF SITES[1]

	MARINE		FRESHWATER	
	Existing	Applications*	Existing	Applications
TYPE				
FINFISH				
Hatcheries	---	---	44	N/A
Growout	211	266	62	N/A
SHELLFISH				
Hatcheries	2	1	---	---
Growout	414	109	---	---
MARINE PLANTS				
Growout	6	3	---	---
Subtotals	633	379	106	---
TOTAL EXISTING	739			

Total existing and applications = 1,118

* Includes Investigative Permits and applications for all forms of Crown land tenures.

1 Based on March 1989 data.

APPENDIX 3
Section 1

AQUACULTURE LICENSING

A. RELEVANT SECTIONS OF THE FISHERIES ACT (R.S.B.C.) AND COMMENTARY

PART 1 - GENERAL PROVISIONS

Interpretation

1. In this Act

> "conservation officer" means a conservation officer under the Wildlife Act.

Conservation officers may require aquaculture licenceholders to produce, upon request, the records referred to in Section 20 of the Act.

> "fish" means the whole or any part of an aquatic animal.

"Fish" include all marine, brackish water and freshwater animals, whether vertebrates or invertebrates, and includes finfish, shellfish and crustaceans.

> "aquaculture" means the growing and cultivation of aquatic plants, as defined in Section 12, or fish, for commercial purposes, in any water environment or in man made containers of water, and includes the growing and cultivation of shellfish on, in or under the foreshore or in the water.

The growing of aquatic plants or animals for any non-commercial purpose (e.g. for personal use), and the holding of live aquatic plants and animals for research or display purposes, or in restaurants and seafood wholesale establishments for resale, do not constitute aquaculture and will not be regulated under this Act. The Ministry of Environment will be issuing Live Fish Permits for these purposes.

2(3) Every officer and constable of the provincial force as defined in the Police Act, and every conservation officer, is by virtue of his office an inspector of fisheries under this Act and has power to act in that capacity in every part of the Province.

2(5) An inspector under the Fish Inspection Act (Canada) and a fishery officer or fishery guardian under the Fisheries Act (Canada) is by virtue of his office an inspector of fisheries under this Act.

By virtue of Section 2(3) and 2(5), every officer and constable of the provincial force (the R.C.M.P.), inspector of fisheries (provincial), fishery inspector (federal) and fishery officer (federal) can require aquaculture licenceholders to produce the records referred to in Section 20 of the Act.

PART 3 - LICENSING OF AQUACULTURE FACILITIES, FISH AND AQUATIC PLANT PROCESSORS AND FISH BUYING STATIONS

Interpretation

12. **In this Part**

> **"aquatic plant" includes benthic and detached algae, marine flowering plants, brown algae, red algae, green algae and phytoplankton;**

This definition includes all aquatic plants except freshwater flowering plants.

> **"coastal waters" includes waters in the fishing zones of Canada adjacent to British Columbia, all waters in the territorial sea of Canada adjacent to British Columbia and all internal waters of British Columbia.**

This definition covers all brackish and marine waters, but may not cover inland freshwater bodies. However, Section 13(4.1) clarifies that anyone carrying out the business of aquaculture "in the Province" or its coastal water must have an aquaculture licence. Legal opinion is that "in the Province" includes all inland freshwater bodies.

> **"establishment" means a place, including a place used for the business of aquaculture, where fish or aquatic plants are handled, processed, graded, stored, grown or cultivated.**

Note: This new definition will be added with the proclamation of the Miscellaneous Statutes Amendment Act (1989).

Licence Required

13(4.1) **No person shall carry on the business of aquaculture at any location or facility in the Province or its coastal waters unless he is the holder of a licence issued for that purpose under this Part and has paid the fee prescribed by the Lieutenant Governor in Council.**

This section provides the legislative prohibition against carrying on an aquaculture business unless authorized by a location-specific licence issued for that purpose. It also allows the Lieutenant Governor in Council to establish a licence fee.

Application for Licences

14. Every application for a licence under Section 13 shall be made in writing to the minister, on a form to be supplied by him, and on receipt of the application the minister may issue a licence.

The minister determines the format and content of an application. It is proposed that each application will include a development plan with different plans for different types of operations and species or species groups. Applications involving Crown land will employ the same development plans as used by the Ministry of Crown lands. Those based on private land will be simplified.

For the initial round of licence issuance, we will be advising all active aquaculture operations of their application requirements. These will differ depending on whether or not a Crown land tenure is involved, development plans exist and if these accurately reflect the current status of the operation. A non-refundable application fee will be required for all applications.

Form of Licences

16. A licence under this Part shall set out

(a) the name and address of the licensee,
(b) subject to Section 15(2), the location of the plant for which the licence is issued or the area in which the licensed activity is to be carried on, or both;
(c) the effective date and the term of the licence; and,
(d) **other terms and conditions as the minister considers appropriate.**

Subsection (d) was added with the proclamation of the Miscellaneous Statutes Amendment Act (1989) in August 1989.

A standard or general set of terms and conditions will be printed on the back of and apply to all aquaculture licences. Additionally, one or more approved development plans will constitute the specific terms and conditions of individual aquaculture licences. Crown land based operations which already have development plans approved by the Ministry of Agriculture and Fisheries will not have to complete new plans in the aquaculture licence application process. However, operations based on private land will have to complete and have approved development plans before aquaculture licences can be issued.

Transfer of Licences

17. **No licence issued under this Part is transferable, except that in the case of a change of ownership of the plant the minister may agree to a transfer of the licence to the new owner.**

As a matter of policy, it is proposed that the minister apply his discretionary power to refuse transfer of licences in favour of the issuance of a new licence to the new operator of an aquaculture facility.

Suspension or Revocation of Licence

18(1) **Where the holder of licence issued under this Part violates any provisions of this Part or the regulations or a condition of a licence, the minister, after due investigation and hearing, if a hearing is requested by the licensee, and on proof to his satisfaction of the violation, may in addition to all other penalties to which the licensee may be liable, suspend the licence and all rights of the licensee for a period the minister thinks fit, or he may revoke the licence.**

18(2) **The minister shall preside at the hearing, and shall have the same powers as the Supreme Court for compelling the attendance of witnesses and of examining them under oath, and compelling the production and inspection of books, documents and things.**

Section 18(1) authorizes the minister to suspend, "for a period the minister thinks fit", or revoke an aquaculture licence should the holder violate any provisions of Part 3 of the Fisheries Act (R.S.B.C.), any regulation made under Part 3 of the Act or any condition of the aquaculture licence. It also clarifies that a licence holder may request a hearing before licence suspension or revocation takes place. Section 18(2) outlines the minister's powers in the conduct of such hearings.

Power to Refuse Further Licence

19. **Where the licence held by any licensee has been revoked, or where it is shown to the satisfaction of**

the minister that a licensee has violated any provision of this Part or the regulations or condition of a licence, or has conducted the business of his establishment in contravention of the spirit and intent of this Part, the minister may, in addition to all other penalties to which the licensee may be liable, refuse after that to issue a licence under this Act to that licensee or to any person for the establishment of that licensee.

This section outlines the power of the minister to refuse to reissue a licence which has been revoked.

Records Kept by Licensees

20(1) A person holding a licence under this Part shall make reports in the manner and form and at intervals specified by the minister.

This section provides for the reporting of such information as the minister may require (e.g. production, inventory, productive capacity, employment) at such time as the minister may require it. This information will be used to evaluate the performance of industry as a whole and the compliance of individual aquaculture licensees with the conditions of their licences. This amended wording will come into force with the proclamation of the Miscellaneous Statutes Amendment Act (1989).

Offence and Penalties

25(2) A person who to contravenes a provision of the Part, a regulation made under this Part or a condition of a licence issued under this Part commits an offence.

25(3) On conviction for contravention of section 13 (1), (2) or (4.1), the penalty is a fine of not less than $500 and not more than $10,000.

25(4) On conviction for contravention of a provision of this Part other than section 13(1), (2) or (4.1), the penalty is a fine of not less than $100 and not more than $2,000.

25(5) On conviction for contravention of
(a) a regulation made under this Part, or
(b) a condition of a licence issued under this Part,
the penalty is a fine of not more than $2,000.

25(6) Each day an establishment is operated in circumstances that constitute an offence under subsection (2) constitutes a separate offence.

25(7) In addition to other penalties or measures taken under this Act or the regulations, all fish or fish products or aquatic plants or aquatic plant products, whether processed or not, on or about an establishment on or after an offence occurs at that establishment, may be seized by a Provincial constable as defined in the Police Act or by an inspector of fisheries and, on the direction of the minister, be forfeited to Her Majesty and sold with the proceeds to be paid into the consolidated revenue fund.

This section provides for fines of $500 - $10,000 for operating an unlicensed aquaculture facility, lesser fines of $100 - $2,000 for violation of other relevant sections of Part 3 of the Fisheries Act (R.S.B.C.) and fines up to $2,000 for violations of the regulations or conditions of a licence. Additionally, Ticket Administration Regulations and Ticket Information Fines Regulations under the Offence Act will, upon amendments and at the direction of the ministry, be used to issue tickets with "voluntary penalties" in the range of $50 - $100 for offences rather than pressing for court summonses.

Further, Subsection 25(7) permits the seizure and sale by the Crown of fish and aquatic plants in addition to other penalties.

Regulations

26(1) The Lieutenant Governor in Council may make regulations.

26(2) Without limiting the generality of Subsection (1), the Lieutenant Governor in Council may make regulations he considers necessary or advisable:

(a) for safe and orderly aquaculture; and,
(b) for safe and orderly distribution of fish and aquatic plants.

APPENDIX 3
Section 2

B. AQUACULTURE REGULATIONS

Interpretation

1. In this regulation

"Act" means the Fisheries Act;

"aquaculture licence" means the licence referred to in section 13 (4.1) of the Act;

"aquaculture facility" means an establishment where the business of aquaculture is carried on;

"attachment structure" means mollusc shell, rope, netting, tubes and other structures provided as substrate for the attachment of aquatic plants and fish for purposes of aquaculture;

"containment structure" means net cages, net pens, tanks, troughs, raceways, natural or manmade ponds, trays and other structures used to contain aquatic plants and fish for purposes of aquaculture;

"fin fish" means fish of the classes Agnatha, Chondrichthyes and Osteichthyes grown by a holder;

"holder" means the person to whom an aquaculture licence is issued;

"location" means

(a) a contiguous area of land that is owned, leased, or otherwise lawfully occupied by a person, and

(b) areas of land whether contiguous or not that are occupied under a single

(i) lease, or

(ii) licence of occupation

granted under the Land Act;

"Contiguous" includes adjoining or abutting parcels of land, ie. the boundaries must touch. More than two contiguous parcels of land may be considered a location for the purpose of this regulation. Parcels separated by any distance, no matter how small, are not considered contiguous and will require separate licences.

"Leased" in (a) above includes private upland leased from its owner, as well as land under the jurisdiction of a Federal Port Corporation or Harbour Commission and occupied under a lease issued pursuant to the Port Corporation Act (Canada) or the Harbour Commission Act (Canada), respectively.

"Land" includes land under water. Lands occupied under authority of the Park Act are also included as are Reserve Lands under the Indian Act (Canada).

Paragraph (b) above is included because of our wish to grandfather several operations that have several parcels of land covered by a single Crown land tenure, and which are operated as a single production unit.

"manager" means the manager of aquaculture appointed under section (6).

Separate licence for each location

2. No person shall carry on the business of aquaculture at a location without first obtaining an aquaculture licence for that location.

The culture of different species or groups of species and the operation of several types of aquaculture facilities (eg. hatchery and growout to food market size) may be covered in a single aquaculture licence, provided they occur within the location defined in the licence. In such cases, several development plans will be attached to and become part of the aquaculture licence. This is in keeping with existing policy and procedure regarding Crown land tenures.

Application for licence and licence renewal

3. An applicant for an aquaculture licence shall make an application to the minister under section 14 of the Act and, where the application is for a renewal of an aquaculture licence, shall deliver it at least 60 days before the term of the existing aquaculture licence expires.

It is our intention to combine the application for renewal with the annual report required under section 20 of the Act. This has been the practise of the Ministry of Environment with regard to the issuance of renewals for its Commercial Fish Culture Permits. This is expected to facilitate timely submission of annual reports. The combined renewal application-annual report form will be mailed to all licensees at least three months before licence expiry. Licensees will have at least one month to complete and deliver the form to the address given in the instructions which will accompany the form.

"Delivered", in the Interpretation Act, with reference to a notice or other document, includes mail to or leave with a person, or deposit in a person's mail box or receptacle at the person's residence or place of business.

Failure to deliver the application for renewal at least 60 days before licence expiry will result in applicants having to reapply for a licence; ie. to submit an application form and fee in addition to the annual report form and licence fee. Thus, there will be a dollar savings for those who submit an application at least 60 days before licence expiry.

Staff will have two months to review and validate annual reports, determine eligibility for Bona Fide Aquaculturist Certificates (BFAC) and prepare licence renewals and BFAC's for mail out. Should government workload preclude renewing licences before the expiry date, the Common Law "Doctrine of Administrative Necessity" would ensure that holders would be legally able to continue under the old licence.

Term of licence

4. An aquaculture licence is valid for a 12 month period from the date on which it becomes effective.

While licences are valid for one year, all licences will not have the same effective date. Licensing of existing operations will be spread out over as much as a six month period, with commodity groups (salmon, shellfish, trout) being licensed within consecutive two month periods.

New operations will be licensed as the application reviews are completed.

This will keep licence administration costs (hence application and licence fees) to a minimum, since fewer staff will be required to process the approximately 800 applications which are anticipated.

While licence renewal and annual report forms will be submitted throughout the year, the requirement for production of calendar year-based production statistics still exists. Both needs will be met by amending the format and content of the annual report forms. It is anticipated that most data requests not directly related to regulatory requirements will be deleted, particularly for fin fish farming operations. Volume and value of product, by species, will be requested for each month. The first report will cover more than a 12 month period, since it will have to provide data from January 1989 to the licence effective date. Additionally, the first annual reports will cover the first nine months of the licence valid period. Thereafter, the annual report will cover a 12 month period, including the last three months of the licence valid period of the first licence and the initial nine months of the first renewal licence. Applicants should therefore ensure that their records keep track of the volume and value of product, by species, on a month-by-month basis.

Statistics regarding productive capacity (eg. net cage or pond volume, meters of longlines) and livestock inventory will be requested as of a particular date, probably December 31st each year.

Dealing in fish or aquatic plants

5.(1) A person shall not possess, buy, sell, introduce into the Province or transplant within the Province, fish or aquatic plants for the purpose of carrying on the business of aquaculture unless the person is a holder or is acting on behalf of a holder.

This subsection clarifies that only those persons having a valid aquaculture licence, or their agents (including employees or brokers acting on behalf of a holder) or independent contractors, may possess, buy, sell, introduce into or transplant within the Province, aquatic plants or fish for purposes of carrying on the business of aquaculture.

If a licensed aquaculture facility is placed in receivership, the Ministry of Agriculture and Fisheries will, as a matter of policy, treat the Receiver-manager as the holder for the duration of the licence term. Should the licence expire before another person has secured the right to occupy the location specified in the licence, the Receiver-manager will have to apply for a licence renewal. Subsequently, the Receiver-manager will have to request that the Minister transfer the licence to a new person once that person has secured the right to occupy the location specified in the licence.

In the more infrequent event of foreclosure of an aquaculture facility by a financial institution, the Ministry of Agriculture and Fisheries will, as a matter of policy, require that the holder and the financial institution apply to the Minister for a transfer of the licence to the foreclosing financial institution. Permission to transfer the licence will not unreasonably be withheld.

Holders should note that <u>this subsection does not authorize the introduction into or transplanation within the Province of fish. An Import Permit or Transplant Approval issued under the Fisheries Act (Canada) are the authorizing implements for these activities</u>. An aquaculture licence will, however, become prerequisite to obtaining such authorizations since it identifies persons as being commercial aquaculturists.

A person in the business of transporting smolts or live-hauling salmon to a processing plant would not, for example, require an aquaculture licence since the person's business is transportation, not aquaculture as defined in the Act. However, transport companies may not transfer live fish from one fish farm to another or to a processing plant unless authorized to do so by the Transplant Committee and must conform to section 9 of these regulations. The Committee is currently devising simple guidelines to accommodate this. By completing and signing a Transfer Permit, a holder will, in effect, transfer to a carrier the holders authority to transport live fish. A separate Transfer Permit, showing source, destination, species, carrier and pick up and delivery dates must accompany each delivery of fish.

(2) Subsection (1) does not prevent a person who has taken the fish or aquatic plants as collateral for a loan from seizing or disposing of the fish or aquatic plants or otherwise realizing on the person's interest in the fish or aquatic plants to satisfy the obligations secured by them.

This subsection was added to ensure that persons could take possession of and sell fish or aquatic plants which are given as collateral for a loan, without those persons requiring an aquaculture licence. Transplant Committee approval would, however, be necessary for any transfer of the seized fish to a processing plant or another fish farm.

Manager of aquaculture

6. The minister may appoint a person in the Ministry of Agriculture and Fisheries as manager of aquaculture.

The manager of aquaculture will be named to provide holders with a key contact in the Ministry of Agriculture and Fisheries. The manager is the person to whom holders must report releases of fish or aquatic plants and the results of any recapture attempts (see section 7).

Special proviso schedules attached to aquaculture licences will identify other instances where holders must contact the manager of aquaculture before or within a specified time after certain actions are initiated. For example, fish farm operators in the Sechelt Inlet system will be required to advise the manager before, or within one day of, initiating the relocation of netcages to designated "emergency relocation areas", as provided for in the Sechelt Inlets Coastal Strategy, in the event that heavy plankton blooms threaten to kill their fish stock.

Release and escape

7.(1) No person shall release aquatic plants or fish to fresh or tidal waters from an aquaculture facility or from containment or attachment structures in an aquaculture facility unless authorized to do so by the terms or conditions of an aquaculture licence.

This section prohibits the release into public waters of aquatic plants or fish from an aquaculture facility unless authorized to do so by a term or condition of an aquaculture licence. The provision for such an authorization is made because it is possible that deliberate release may be desirable in certain very specific circumstances. For example, it is already acceptable practise to release into public waters, for stock enhancement purposes, salmonid smolts raised in private sector hatcheries. Currently, the actual release may be conducted by government personnel but it is possible that commercial aquaculturists may effect releases in the future. <u>Holders must ensure that they have obtained additional authorization from the Transplant Committee or any other prescribed governmental authority BEFORE effecting a release.</u>

(2) A holder shall take reasonable precautions to prevent the escape of aquatic plants and fish from the holder's aquaculture facility and from containment and attachment structures in the facility.

A holder is expected to apply existing methods and equipment to prevent the escape of livestock. Those found grossly negligent would be subject to prosecution.

Reporting escape

8.(1) The holder, or person acting on behalf of the holder, who discovers an escape or evidence suggesting an escape of aquatic plants or fish from an attachment or containment structure in the holder's aquaculture facility shall report the escape or evidence to the manager

> **(a) verbally, within 24 hours of the discovery, and**
>
> **(b) in writing, within one week of the discovery, if requested by the manager.**

This section establishes both the requirement and the process for reporting escapement of aquaculture livestock, including fish, shellfish and aquatic plants. Holders will be responsible for ensuring farm staff are aware of this requirement and take the steps necessary to ensure that the manager of aquaculture is notified within the time limits specified above. This section does, however, make agents (including employees) and independent contractors who are operating the licensed facility for the holder responsible for reporting escapes.

(2) A holder who recaptures or attempts to recapture aquatic plants or fish that have escaped from an aquaculture facility shall report in writing the results of the recapture, or attempted recapture, to the manager within one week of the recapture or attempted recapture.

It is recognized that aquaculture liverstock may be intentionally (eg. by vandals) or accidentally (ie. due to human error, equipment failure or such natural events as severe storms or tsunamis) released.

<u>BEFORE attempting to recapture fin fish which escape from fish farms, holders MUST:</u>

> 1. <u>notify the District Fisheries Officer of the federal Department of Fisheries and Oceans (DFO) of the escape, and</u>
>
> 2. <u>be issued a special permit by that Fisheries Officer</u>.

<u>DFO advises that it will require notification of any escape within 24 hours of discovery</u>.

It is understood that the Department will issue these permits to particular vessels to effect the recapture. The vessels could be owned by holders or their employees, or by independent contractors to the holder. Guidelines for issuance of these permits have yet to be established.

Where fin fish escapes occur into freshwater, it is anticipated that the Ministry of Environment and the Ministry of Agriculture and Fisheries will be involved in the permit issuance process as well as in the guideline development process.

It is acknowledged that bottom-cultured oysters and aquatic plants could, under certain rather unusual circumstances, "escape" from an aquaculture facility. Once beyond the boundaries of the facility such livestock become, in any practical sense, indistinguishable from wild stocks which are managed by the Ministry of Agriculture and Fisheries. Therefore, BEFORE a holder recaptures or attempts to recapture oysters or aquatic plants which are carried, by such natural forces as heavy wave action and strong current flow, beyond the boundaries of an aquaculture facility, the holder MUST, in addition to notifying the manager of the release, obtain an oyster harvesting permit issued under the Fisheries Act Regulations or a licence issued under section 24 of the Act. These may be obtained from the Ministry of Agriculture and Fisheries and are subject to payment of fees as required by regulation.

Nothing in this section prevents a holder from retrieving containment or attachment structures and the aquaculture livestock contained therein or attached thereto, which have broken free of their moorings, and resecuring these within the boundary of the aquaculture facility.

Transportation

9. A person who transports aquatic plants or fish on, over or through fresh or tidal waters shall take reasonable precautions to prevent the escape of the plants or fish, as the case may be.

This subsection requires any person who transports aquaculture livestock to employ due diligence, that is use available methods, equipment and surveillance, to prevent the escape of the livestock being transported

Inspectors

10.(1) The minister may appoint any person as an aquaculture inspector to investigate matters related to

(a) the conduct of the business of aquaculture, and

(b) compliance with the Act, this regulation and an aquaculture licence and its conditions.

(2) An aquaculture inspector may enter an aquaculture facility during normal business hours to investigate the matters referred to in subsection (1) and no person shall obstruct the inspector in the course of the inspector's duties.

No person may obstruct the entry of an inspector to an aquaculture facility during normal business hours, nor may anyone obstruct an inspector as the inspector carries out his/her duties. Aquaculture inspectors will be uniformed in some way and will carry photographic identification cards.

(3) At the request of an aquaculture inspector, an inspector of fisheries or a conservation officer, a holder shall produce for inspection a record that is required to be produced for inspection as a condition of an aquaculture licence.

It will be a condition of all aquaculture licences that holders keep records sufficient to allow an inspector to determine whether or not the holder is complying with the development plans which are part of the aquaculture licence. Further, holders will, as a condition of licence, be required to produce such records for inspection within 24 hours of an inspectors request.

Fees

11.(1) In Appendix 1

"primary aquaculture product" means a fish or an aquatic plant that is a product of aquaculture but does not include a processed or manufactured product;

"production value" means the dollar value of sales of primary aquaculture product in the previous licence year, but where the terms and conditions of the aquaculture licence contain a maximum volume of production equivalent to a dollar value, it means that dollar value.

This definition creates a parallel between the eligibility criteria for Bona Fide Aquaculturist Certificates (BFAC)and the criteria for distinguishing between larger and smaller scale aquaculture operations. Since BFAC's will not be issued for locations which produce less than $7,500 of primary aquaculture product each year, the lesser fees charged smaller scale operations are justified based on reduced administrative work load.

(2) A person applying for a new aquaculture licence, a renewal of an aquaculture licence or an amendment of an aquaculture licence shall pay the fee set out in Appendix 1.

(3) Subject to the Financial Administration Act, the fee for an application for a new aquaculture licence and the fee for a licence amendment are not refundable.

APPENDIX 1

Schedule of Fees

1. Application for initial licence	$25
2. Licence amendment	$50
3. Licence and licence renewal for	
a. aquaculture facility on private land, production value at least $7500	$100
b. aquaculture facility on private land, production value less than $7500	$50
c. aquaculture facility on Crown land, production value at least $7500	
i. aquatic plants and fish other than fin fish	$150
ii. fin fish	$200
d. aquaculture facility on Crown land, production value less than $7500	
i. aquatic plants and fish other than fin fish	$50
ii. fin fish	$100

GENERAL TERMS OF AN AQUACULTURE LICENCE

1. For the purpose of this licence

"Branch" means the Aquaculture and Commercial Fisheries Branch of the Ministry of Agriculture and Fisheries, and

"Development Plan" means a plan filed with and approved by the Branch for the species and location specified on the face of this licence.

2. The holder of an Aquaculture Licence shall

2(1) comply with the management and operating specifications in each Development Plan;

2(2) apply for and have approved amendments to a Development Plan before (a) increasing or decreasing production or productive capacity by more than 20% from that currently authorized or (b) changing the mode of operation currently authorized;

2(3) culture or husband only those species authorized by this licence, and only if importation and transplantation authorizations have been obtained from all competent governmental authorities;

2(4) take reasonable precautions to prevent the escape of aquatic plants or fish (a) if transporting aquatic plants or fish on, over or through fresh or tidal waters, and (b) from the holder's aquaculture facility and from containment and attachment structures in the facility;

2(5) ensure that neither the holder nor any person acting on behalf of the holder deliberately releases fish or aquatic plants from the holder's aquaculture facility, unless authorized to do so by the terms and conditions of this licence;

2(6) ensure that the holder or a person acting on behalf of the holder who discovers an escape or evidence suggesting an escape of aquatic plants or fish reports the escape or evidence and the results of any recapture or recapture attempt to the Manager of Aquaculture;

2(7) ensure that the aquatic plants and fish cultivated and husbanded in the holder's aquaculture facility are given care and attention consistent with their biological requirements for good health and well being;

2(8) undertake at the holder's own expense, reasonable husbandry practises necessary for (a) preventative predator control and (b) prophylactic disease control and diagnostic disease treatment, including that required by competent governmental authorities;

2(9) keep records adequate to allow an Aquaculture Inspector, an Inspector of Fisheries or a Conservation Officer to determine if the holder is complying with the terms of this licence including, but not limited to, those described in any Development Plans;

2(10) make available to an Aquaculture Inspector, an Inspector of Fisheries or a Conservation Officer, the records referred to in sub-paragraph 2(9) within 24 hours of a request being made;

2(11) advise the Manager of Aquaculture within one week of any change in the holder's (a) address, (b) telephone, radio telephone or facsimile machine number, and (c) representative (contact person) and that person's telephone, radio telephone or facsimile machine number;

2(12) deliver to the Branch, in the form and at the interval determined by the Minister, any information required to determine compliance by the holder with the terms of this licence, and any other information that the Branch requires to evaluate trends and practises of the aquaculture industry as a whole;

2(13) apply for and possess a valid processing licence before processing aquatic plants or fish within the location specified on the face of this licence;

2(14) ensure that the aquaculture facility is operated in accordance with standards established by the Branch;

2(15) comply with all laws, bylaws and orders of any competent governmental authority which affects the aquaculture facility described herein.

3. If the holder of this licence fails to perform any obligations in this licence, the Minister may, in addition to other penalties in the Fisheries Act (R.S.B.C.) and the Aquaculture Regulations, suspend or cancel this licence and refuse to reissue an aquaculture licence to that holder or to any person for the establishment of that holder.

4. This licence is not transferable except with the written permission of the Minister.

5. This licence does not abrogate, replace, or derogate from any of the rights, powers or jurisdictions of the Province of British Columbia or the Ministry of Agriculture and Fisheries.

APPENDIX I

LAND-BASED TANK FARMS

LAND-BASED TANK FARMS

A recent development in the culture of salmon is the rearing of fish on shore in large tanks. Sea water is continuously pumped through the tanks or raceways and discharged back into adjacent marine waters. Experimental culture of Atlantic salmon in Iceland has demonstrated the feasibility of this culture method. However, wide-scale commercial operations are just being initiated. Thus, the method must be still considered experimental, but one which may provide an alternative method of fish culture in some areas and situations.

The primary advantage of tank farms to the fish grower is that he has much greater control over the water and the fish culture environment. By selecting the depth of the water source, the farmer can avoid noxious plankton, and have limited control of temperature, salinity, and dissolved oxygen. He can also control flow rates through the tanks to provide optimal growing conditions, and may add supplemental oxygen or air to the water to allow higher stocking densities and lower disease risks. Other advantages include the ability to work in any weather, avoidance of many of the potential conflicts with other water users, and avoidance of predator problems. Tank farms also provide the opportunity for treatment of the effluent in areas that may be sensitive to nutrient enrichment.

Disadvantages of tank farms include the higher construction and operating costs to pump water. Perhaps the greatest disadvantage is the limited availability of suitable sites, which must be flat, near water, and close to sea level to minimize pumping requirements.

The following discussion briefly describes tank farms and the potential environmental impacts of this culture method which, in some situations, may provide an alternative method of fish culture to fish farms.

The primary features of a land-based system include:

- An intake pipeline located subtidally to provide a constant supply of high quality water
- A pump and delivery system to circulate water through the rearing tanks
- A series of upland rearing tanks and/or raceways (circular tanks up to 20 m [66 ft] in diameter and 3 m [10 ft] deep appear to be the preferred tank design).

Land-based sites low in elevation and near shoreline areas are preferred. Such locations reduce the length of the intake system, and maintain pumping efficiency by limiting the pumping head (the vertical height water must be pumped to supply the rearing ponds). In addition, tank farms should be located in areas free of plankton blooms and near relatively deep water where water can be drawn from below any blooms.

The physiological requirements of salmon reared in tank farms are the same as those of salmon reared in fish farms. However, because of different rearing conditions and economic considerations, there are notable differences in the two technologies in terms of rearing densities and operation and maintenance procedures. These differences are projected to have a significant affect on the quality of the discharge.

The most notable difference between the two technologies may be the amount of feed required for production of an equivalent amount of fish. Average food conversion ratio (FCR) in net-pen facilities may vary from 1.5 to 1 (Hardy 1988, personal communication) to 2.0 to 1 (Weston 1986). Recent work suggests that a FCR of 1.2 to 1.0 or less may be achieved (Asgard et al. 1988). This ratio accounts for conversion of feed to fish flesh (dry pellets of 10% moisture compared to fish flesh of 70% moisture) as well as loss of feed (a 0-20% loss of the feed depending on the site location, type of feed, and rearing practices), loss of fish due to mortality, or other reasons. Since onshore tank farms use circular tanks with controlled flow and oxygen conditions, proponents claim that salmon are able to feed and convert fish feed more efficiently to flesh than in fish farms that are subject to variations in water velocity and existing oxygen conditions. As the FCR improves (lower ratio), the amount of waste food and total solids loss drops significantly.

Other positive aspects of land-based tank farming include the relatively high quality of waste water that is a result of dilution by the large volume of water flow necessary in the tanks. Since self-cleaning tanks may be designed, "shock loads" due to sudden discharges of large amounts of organic waste during cleaning may be avoided. Stocks of fish may be separated for disease isolation and treatment. Routine addition of oxygen may improve dissolved oxygen levels relative to existing source water conditions. This extra oxygen allows higher stocking densities and reduced incidence of disease.

Potential negative impacts of land-based tank farming include release of a more concentrated effluent than fish farms. Because large volumes of flow are necessary for land-based tank farms, the concentration of pollutants such as ammonia in the effluent may be low, but not as low as that seen from fish farms. The National Pollution Discharge Elimination System (NPDES) permit system administered by the Washington Department of Ecology requires that effluent receiving waters must have active hydrodynamics to allow dispersion of the solid and dissolved wastes. Due to salt content, solids isolated from onshore tank farms are not readily disposable on land as fertilizer or fill. Depending on its design and site, land-based tank farms may need to screen their intakes to prevent fish from being taken up in the intake.

In general, land-based rearing of fish allows for tighter control over all phases of outgrowing (growth to marketable size) compared to fish farms. In a land-based system, water flow rates and dissolved oxygen concentrations (variables important to fish health) can be adjusted depending upon the fish rearing requirements. In addition, fish reared in tanks are easily observed and sampled. This accessibility to the fish helps develop efficient feeding schedules, identify stress and disease, and aids in the treatment of fish if a fish disease or parasite is identified.

On the other hand, land-based tank farms are more costly to construct and operate than a fish farm system. Unlike fish farms, tank farms need intake and outlet structures, as well as rearing ponds. Greater operational costs also occur with tank farms due to maintenance of the rearing facilities and the cost of pumping and circulating rearing water.

The successful operation of a land-based facility is, therefore, dependent upon efficient management and close control over the rearing process. Compared to fish farm operations, land-based facilities can potentially increase overall survival, improving harvest rates, as well as improving feed conversion ratios which result in decreased feed costs.

While there are no operating land-based tank farms in Puget Sound, upland systems have been proposed for Grays Harbor and Clallam Counties, and other areas of the United States and Canada. Saltwater tank farms are successfully operating in western Europe and Iceland. Upland tank farms are a new technology and have yet to be fully proven economically. They appear, however, to offer an alternative means of growing fish which may complement fish farming, and provide an alternative to fish farms in situations where fish farms would otherwise be impossible.

Land-based tank farms must comply with all local, state and federal regulations pertaining to fish farms, with the possible exception of the ArmyCorps of Engineers permits concerning navigation. In addition, tank farms, as sources of point-source discharge, are subject to permitting requirements under the National Pollutant Discharge Elimination System.

The following discussion briefly summarizes the possible environmental impacts of upland tank farms for the purpose of comparison with fish farm culture.

1. SEDIMENTATION

Tank farms can introduce sediment into the marine environment through discharge pipes at an outfall. Unlike fish farms, the fish farmer can regulate the effluent from the facility. Feces and excess feed frequently will settle to the bottom of the tanks where they can be removed, or be collected in settling ponds.

Any sediment which is discharged from a tank farm would affect the marine environment in a manner similar to the sediment deposited from a fish farm facility or similar discharges. Unlike fish farms, which by their size provide a vast area for dispersal, tank farm discharges are a point source which would concentrate sediment impacts without adequate sediment removal or adequate dispersal of the discharged material.

A range of responses, similar to those described for fish farms, will occur at the effluent outfall. Where effluent is rapidly and effectively dispersed, the effects will range from local enrichment of the bottom community to no noticeable change. If dispersion is minimal, the effects will be substantial, as all of the sedimentation will occur in a concentrated area. Dispersion can be increased by placement of the discharge pipe in areas of high current flow, and through the use of diffusers on the end of the pipe.

2. WATER QUALITY

The potential water quality impacts from land-based tank farms will be like those from floating fish farms. Because of the relatively small volumes of water in tank farms, the dissolved oxygen concentration in the discharge water may be reduced. Data from 38 fresh water tank farms in Europe were used to calculate an average decrease in dissolved oxygen of 1.6 mg/L through the facilities (Alabaster 1982). As a worse-case approximation, a decrease of 2 mg/L through a land-based tank farm, and an initial concentration of 6 mg/L would require a minimum dilution factor of about 10 to meet the state standard (5.8 mg/L in this case). A dilution factor of 10 would likely be achieved in close proximity to a land-based tank farm outfall. Tank farms also have the potential to aerate or oxygenate water entering and leaving the tanks. This can improve the culture environment for the fish, as well as offset any oxygen demand from the fish or the discharged nutrients.

Land-based tank farms are subject to the same nutrient enrichment considerations as floating fish farms. That is, restricted embayments with nutrient sensitivity should be avoided for both the good of the cultured fish due to dinoflagellate blooms, and for the possible enrichment effect upon algae or phytoplankton in the discharge waters. The three onshore tank farms proposed or being built in Washington state are located in non-nutrient sensitive waters. As in fish farms, about 70% of the nutrients are discharged in solution. Retention time of water within the tank farms will generally be less than two hours, and the water is actively moving in the tanks and pipes. Both the period of time and movement of the water are not conducive for the development of optimum algal growing conditions. Site characteristics, especially the physical oceanography, depth of intake and discharge, and the density of water at both intake and discharge depths will greatly influence the fate of discharged waste water.

Chemical usage in tank farms would generally be less than in fish farms, again because the tank farm operator has much greater control over the culture environment. Antibiotic use would probably be less because the farmed fish will not be directly exposed to disease carrying wild fish, and the controlled culture environment reduces the probability of disease and permits easier control of any disease outbreaks. In addition, it is likely that tank farms would not use large amounts of antifoulant materials. The use of any chemical in tank farms would have impacts on the aquatic environment similar to those described in Section 5.4, Chemicals.

3. FISH AND SHELLFISH

The primary impacts of fish farms on fish and shellfish are the possible smothering of sessile (immobile) organisms below the farms, if the farms are located in shallow, poorly flushed areas, and the attraction of mobile fish and shellfish species to the site. Because tank farms would have a much more concentrated discharge, the area of bottom affected would be less than for fish farms, and the potential impact of sessile bottom-dwelling organisms would be reduced. Construction of the intake and outfall structures, however, could destroy shellfish beds in the construction area. Because shellfish populations usually occur in discrete beds, proper site selection can avoid significant impacts for clams, oysters, geoducks, etc.

In the absence of a significant structure in the water, the attraction of fish and shellfish to the site would be reduced or eliminated. Fish could be adversely affected if entrained in the intake pipe; therefore, proper screening of the intake will be necessary. It will also be necessary to avoid areas of intertidal herring and smelt spawning or important habitats for other fish species. Because the location of all these habitats is unknown, field observations will be necessary to determine which species use the area and if important habitats would be affected.

The potential for fish to escape into the wild from tank farms is relatively remote compared to fish farms. Even in the event of a major catastrophe (for example, a tank ruptures during a large earthquake), most fish would be stranded on dry ground and die. If fish were to escape, the impacts to wild populations would be the same as for fish farms.

4. WILDLIFE

Construction of each land-based tank farm could result in the loss of several acres of upland habitat, depending upon the previous use of that land.

Most of the habitat loss would be due to construction of the rearing tanks and support facilities such as operations buildings and new access roads. Clearing of vegetation would remove habitat, and may result in losses or displacement of small vertebrates such as mice, snakes, and frogs. Larger animals such as river otter, deer, raccoon, beaver, and birds may temporarily avoid construction sites. Noise generated by farm construction and operation may temporarily displace or disturb nearby wildlife. Consultation with fish and wildlife agencies during permit review is required to avoid affecting the habitats of any threatened or endangered species. Stretching netting over the top of upland facilities is an effective technique for keeping predators away from the fish.

5. ODORS

Operation of a land-based tank farm facility would be less likely to produce odors than would a floating fish farm facility because of the absence of nets and their associated fouling organisms, and the availability of enclosed storage areas for food. Minor odors could result from diesel engines used for emergency pumping during power outages, or from trucks servicing the facility. All odor impacts would be occasional and intermittent. As with floating fish farms, dead fish could create unpleasant odors if not removed from the tanks and disposed of properly. Because tank farms are located on shore, they may be closer to residents than fish farms. Consequently, any odors produced may have a greater effect on these residents.

6. NOISE

Sources of noise at land-based tank farms would be similar for any small agricultural or commercial activity. Large pumps and compressors would be required for aeration and pumping. These would be electrically powered and enclosed in buildings or located below grade, and would probably produce little detectable noise off the farm property.

Land-based tank farms would be required to meet the relevant local and state noise standards. In rural areas with low existing noise levels, noise levels meeting state standards may be disturbing. In such areas, additional mufflers, sound enclosures, or buffer zones could be used to minimize any disturbance of nearby residents.

7. UPLAND AND SHORELINE USE

Land-based tank farms have the same requirements for high quality water as floating operations, and will provide ongoing monitoring of water quality. Other shoreline activities adversely affecting water quality would harm the fish culture operations. As in the review of any proposed activity, new projects near the tank farm would be evaluated for their effect on existing activities and their impacts on water quality and other elements of the environment.

Activity levels associated with an upland tank farm will be similar to those of a small farm or commercial facility. Increased vehicle traffic from employees travelling to and from work, and from deliveries of food and other supplies and shipments of harvested fish will occur. In some cases, the farms may also attract visitors and tourists. The number of trips will depend upon the size of the facility and its proximity to suppliers. In addition, land-based tank farms may have other commercial elements, such as fish processing, which must be considered.

8. AESTHETICS

The extent of aesthetic impacts resulting from tank farms will vary depending on the site, especially the existing activities and structures in the area, and the visibility of the facility to outside observers. Highly visible tank farms may be perceived as visually intrusive in rural or natural areas, yet be unobtrusive at sites surrounded by industrial or commercial uses.

Aesthetic impacts in sensitive areas can be minimized by providing for adequate setbacks from adjoining properties and by providing landscaping to visually shield land-based facilities from nearby observers.

9. RECREATION

Recreational activities would not be impacted by land-based tank farms, except where the facility displaced existing shore-based use. If the beach is privately owned, recreational use by the public would be allowed only with the owner's permission. If the beach is publicly owned, intake and discharge pipes could be buried to avoid any conflict with existing use, except during construction.

10. LOCAL SERVICES

The impacts of land-based tank farms on local services are expected to be similar to the impacts of floating fish farms and would not be significant. Tank farms would have more demand on local services such as electricity, roads, and fire protection. They would also be subject to local property and other taxes which currently do not apply to fish farms.

APPENDIX J

LEGISLATION AUTHORIZING THE EIS

General Fund Appropriation	$	602,000

The appropriation in this section is subject to the following conditions and limitations: $182,000 is provided solely for carrying out the Puget Sound water quality plan.

NEW SECTION. Sec. 309. FOR THE PUGET SOUND WATER QUALITY AUTHORITY

General Fund Appropriation	$	2,910,000
Water Quality Account Appropriation	$	1,100,000
Total Appropriation	$	4,010,000

NEW SECTION. Sec. 310. FOR THE DEPARTMENT OF FISHERIES

General Fund Appropriation——State	$	47,465,000
General Fund Appropriation——Federal	$	14,057,000
General Fund Appropriation——Private/Local	$	3,651,000
Aquatic Lands Enhancement Account Appropriation	$	425,000
Total Appropriation	$	65,598,000

The appropriations in this section are subject to the following conditions and limitations:

(1) $106,000 of the general fund——state appropriation is provided solely for carrying out the Puget Sound water quality plan.

(2) $40,000 of the general fund——state appropriation is provided solely for the purposes of reintroducing an early coho salmon run to the Tilton river and Winston creek.

(3) $587,000 of the general fund——state appropriation is provided solely for implementing the timber, fish, and wildlife agreement. If Senate Bill No. 5845 is not enacted by June 30, 1987, the amount provided in this subsection shall lapse.

(4) $150,000 of the general fund——state appropriation is provided solely for shellfish enforcement on Hood Canal.

(5) $150,000 of the aquatic lands enhancement account appropriation is provided solely for the preparation of an ecological impact statement on the guidelines for the management of salmon net pens in Puget Sound.

(6) The department shall present to the natural resource committees of the senate and house of representatives no later than February 1988 a report on the department's watershed plan, with specific identification of the benefits associated with the Queets hatchery and other Indian tribal agreements.

(7) $194,000 of the general fund——state appropriation may be expended for additional feed for the Deschutes hatchery.

(8) $400,000 of the general fund——state appropriation is provided solely for the purpose of a comprehensive biological study conducted by the department in conjunction with the University of Washington and Grays

APPENDIX K

EFFECT OF FISH FARMS ON SURROUNDING PROPERTY VALUES

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(206) 683-7084

REPORT - FLOATING SALMON NET PENS

SITE #1: PEALE PASSAGE - Mason County, WA.
Township 20 North, Range 2W, W.M.

DATES OF INSPECTION: August 10 and 11, 1988, February 15, 1989

PURPOSE AND FUNCTION OF REPORT: The purpose of this report is to determine the effects, if any, of floating salmon net pens on the surrounding upland property values. The function is to provide information useful in siting floating salmon net pens.

CERTIFICATION AND LIMITING CONDITIONS: The Standard Certification and Limiting Conditions are attached.

AREA DESCRIPTION: Peale Passage is located between Squaxin Island and Hartstene Island in Mason County, Washington. The width of the passage varies from about 500 feet at its north end to about 4300 feet in the vicinity of the existing fish pens. Squaxin Island, along the west side of Peale Passage, is an Indian Reservation and is basically undeveloped. Access is gained by boat. Hartstene Island is to the east of Peale Passage and is connected to the mainland by a bridge built in 1969. A majority of the residential development on the island has taken place since 1969 as a result of the accessibility and the inflating property values of the mid to late 1970's in western Washington. Hartstene Island's development is mainly along the waterfront. The upland areas are for the most part still used as forest land.

Because Squaxin Island is an Indian Reservation and Hartstene Island has only been readily accessible for the past 20 years, much of the land along Peale Passage is still relatively undeveloped.

Floating salmon net pens were first installed in Peale Passage by the Squaxin Indian Tribe in 1971. Additional floating net pens were put into operation by the Washington State Department of Fisheries and the Squaxin Tribe in 1982 and 1986.

TOPOGRAPHICAL INFORMATION: The southwest portion of Hartstene Island has very low lying terrain with a maximum of 277' feet of elevation in the area directly east of the net pens. I traveled most of the accessible roads in the Southeast portion of Hartstene Island and found no sites where the net pens were visible other than along the waterfront. These waterfront sites were all under 40 feet in elevation. The dense vegetation and lack of upland development precludes seeing the water in Peale Passage from other than along the shoreline.

Squaxin Island was not visited by this appraiser.

SIZE AND DESCRIPTION OF PENS: The most northerly pen complex is 69.5 feet x 320 feet and covers about one-half acre of water surface. The middle pens are 329 feet x 110 feet and cover about .83 acres of water surface. The most southerly pens are 69.5 feet by 320 feet and cover about one-half acre of water surface. There are several barges anchored near the pens which serve as support structures for the pens. The elevations of these structures vary from 12.5 feet to 25 feet above the water surface.

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VISIBILITY OF PENS FROM HARTSTENE ISLAND: The actual floating net pens were not visible from any of the sites visited on Hartstene Island. The orange anchor balls in the vicinity of the pens were visible and the support structures were visible. From Hartstene Island it was difficult to tell if these support structure were floating or built on shore.

PROPERTY VALUES: Sales of both improved and unimproved real estate on Hartstene Island, from which the fish pens might be visible, were researched. Sales of similar properties from other areas of Hartstene Island were also researched. Mason County appraiser Darryl Cleveland provided information gathered by the County Assessor's Office in their recent re-evaluation of Hartstene Island. Several local real estate offices and individual property owners having 'For Sale' signs were contacted to determine current asking prices for parcels in the area bordering Peale Passage as well as other similar areas in Mason County.

CONCLUSION: The appraiser found normal variations in front foot values for waterfront lots based on the type of road access, availability of utilities such as a water system, height of bank at the waterfront, etc. The data gathered indicates that properties having similar characteristics sold for similar amounts without regard to their location on Hartstene Island.

Three new homes are under construction at the present time on the southwest side of Hartstene Island in the area nearest to the floating net pen sites. This further indicates the pens have not inhibited the development of new homes in this area.

Property values based on sales history show a rapid appreciation all over Hartstene Island in the mid 1970's. In the years between 1983 and 1986 property values decreased uniformly all over Hartstene Island as they did generally in this part of Washington.

In fact in 1987 the Mason County assessors office collected data on sales of low bank, medium bank and high bank waterfront from all areas of the island. As a result of this study the assessed value per front foot of waterfront was lowered in all three categories without regard to their location on the island.

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After examining the comparable sales data from different areas of Hartstene Island and similar waterfront parcels in Mason County, it is the opinion of this appraiser that the Peale Passage floating net pens have had no effect on property values in this area.

It is also the opinion of the appraiser after visiting various areas and taking photographs from these areas that there is no visual impact, good or bad, from these pens.

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SALES INFORMATION

RESEARCH AREAS ON PEALE PASSAGE - SW SIDE HARTSTENE ISLAND

CHAPMAN ROAD AREA - APPROXIMATELY 5400 LINEAL FEET TO PEN 12025

Lot 1, Sunset Acres PN 22014-50-00001
Community Water - Individual Septic System

1974 - $17,500 as unimproved waterfront lot.
1975 - Building Permit $18,000.
1975 - Added to Assessor Rolls in 1975 as 1.5 story 1593 sq. ft. home with 484 sq. ft. garage.
1984 - Sold for $105,000.

Lot 5, Sunset Acres
1976 Building Permit $30,000.
1976 Added to Assessor Rolls in 1976 as 1.5 story, 2048 sq. ft. home with 672 sq. ft. garage
1986 Sold for $125,000.

MAPLES ROAD AREA - APPROXIMATELY 3300 LINEAL FEET TO PEN 11284

Tract 3 Govt. Lot 2 and Tax 61-D and
Tract 3 of S.P. # 426 100 FF WF
1979 - $29,500 unimproved waterfront lot.
1980 - Building permit $70,590.
1980 - Added to Assessor Rolls in 1980 as a 3 story 1974 sq. foot home.
1983 - Sold for $135,000.

Tract 2 Govt. Lot 2 and Tax 61-C 100 FF WF
1988 - New log home under construction at the present time (photo).
1984 - $55,000 unimproved waterfront lot.
1985 - $63,500 unimproved waterfront lot.

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Tract 4 of Survey 6/5-6 135 FF WF
- 1981 - $65,575 unimproved waterfront lot.
- 1981 - $79,500 unimproved waterfront lot.
- 1987 - $60,000 unimproved waterfront lot.
- 1987 - New home under construction.

Assessed value of improvements

Partially completed	$67,280
Assess. value of lot	$60,700
Total	$127,980

Tract 6 of Survey 6/5-6 110 FF WF
- 1981 - $67,500 unimproved waterfront lot.
- 1986 - New home 50% complete.

Tract 3 of SP #1200 Govt. Lot 5 105 FF WF
- 1983 - $42,500 unimproved waterfront lot.
- 1987 - $39,700 unimproved waterfront lot.

OLYMPIC VIEW TRACTS - 4800-6900 LINEAL FEET TO PEN 11284

RESEARCH AREA ON CASE INLET -E. SIDE HARTSTENE ISLAND

E. SIDE HARTSTENE ISLAND - POINT WILSON
Plat (28 lots) Sec. 20 Twp. 20N, Rge 1W, W.M.

Tract 5 + Tax 1194-A and South 25' Tract 4 and Tax 1194-B-1
Home built 1946
125 FF WF Med. Bank (20 ft.+)
1977 - Sold for $33,500.

This plat consists of older cabins and homes, two or three new homes and a few vacant parcels. There is similar sales activity to the Peale Passage side.

PLAT OF ISLAND SHORES - Govt. Lots 2 and 3, Sec. 18, Twp 20N, Rge 1W W.M.

Tract 6 Island Shores 95 FF WF
Med. Bank (30 '- 50') Brushy with clearing.
1973 - $5,000 unimproved waterfront lot.
1983 - $34,000 unimproved waterfront lot.

Tract 7 Island Shores 100 FF WF
Med. Bank (30' - 50") Brushy - level
1982 - $33,500 unimproved waterfront lot.
1983 - New construction 1272 sq. ft., 1.5 story with deck.

Tract 13 Island Shores 100 FF WF
Med. Bank (30' - 50')
1978 - $20,000 unimproved waterfront lot.
1981 - $42,800 unimproved waterfront lot.

Tract 14 Island Shores 100 FF WF
Med.-Hi. Bank (30' - 50')
1971 - $15,000
1981 - $34,500

Tract 9 Island Shores Plat #2
1987 - $60,000 improved waterfront lot.

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REPORT - FLOATING SALMON NET PENS

SITE #2: RICH PASSAGE - Kitsap County, WA.
Township 24 North, Range 2E, W.M.

DATES OF INSPECTION: August 11, 17 and 18, 1988

PURPOSE AND FUNCTION OF REPORT: The purpose of this report is to determine the effects, if any, of floating salmon net pens on the surrounding upland property values. The function is to provide information useful in siting floating salmon net pens.

CERTIFICATION AND LIMITING CONDITIONS: The standard Certifications and Limiting Conditions are attached.

AREA DESCRIPTION: Rich Passage is located between the south end of Bainbridge Island and the Manchester area on the Kitsap Peninsula. It is the waterway used by the Seattle-Bremerton ferries and the U.S. Navy Shipyards at Bremerton and Keyport.

A large portion of the south end of Bainbridge Island was the Fort Ward Military reservation for many years. Today part of the reservation is a Washington State Park and the balance was sold by the U.S. Government to a private party. There is a row of homes along the waterfront both east and west of the Fort Ward area.

On the south side of Rich Passage the U.S. Government maintains a naval reservation. A Washington State Park adjoins the Reservation on its north boundary. The area north of the State Park is known as Wautauga Beach and is a single family residential area.

Other than along the waterfront, the upland areas on both the north and south side of Rich Passage are largely undeveloped.

According to information from the Washington State Department of Natural Resources Aquaculture Division, floating salmon net pens were first placed in Rich Passage in June of 1971 by the National Marine Fisheries Service. In March of 1972 Domsea Inc. leased a large area on the south side of Rich Passage for placement of net pens. Pens were placed on the north side of Rich Passage by Domsea Inc. in 1974, by Domsea Inc. in 1979 and by Passage Silver Inc. in 1987. Four of these pens are shown on the aerial photo exhibit attached to this report. The fifth set of pens was installed after these photos were taken and its location on the exhibit is approximated from lease information obtained from the Department of Natural Resources.

TOPOGRAPHICAL INFORMATION: The south end of Bainbridge Island has a narrow level area along the waterfront, then a fairly steep brush and tree covered bank that rises to about 100 feet in elevation. The terrain then becomes a gradual slope to about 200 feet in elevation in most areas. The highest point is about 360 feet in elevation.

The accessible areas on the south or Kitsap Peninsula side of Rich Passage have a much more gradual slope up from the waterfront with dense brush and tree cover in most areas.

Photographs were taken from a variety of elevations and locations in an attempt to show the visual impact of the pens from different elevations and distances. All photographs were taken with a 50 MM lens.

<u>SIZE AND DESCRIPTION OF PENS</u>: The four floating net pens as shown on the aerial photograph of Rich Passage scale as follows: Pen number 9780 is approximately 200 feet by 850 feet; Pen number 12584 is approximately 250 feet by 250 feet; Pen number 10237 is approximately 250 feet by 500 feet; the pen on the Environmental Protection Agency (EPA) dock is approximately 200 feet by 150 feet, the Passage Silver Pen was recently installed and the only information regarding its size is the Department of Natural Resources list showing it covers .41 acres of water surface.

These floating net pens in this area are made of a variety of materials ranging from wood to steel. Some of the pens are a mixture of both. The Bremerton East Quadrangle Exhibit has pictures taken of the pens which are attached to the EPA dock at Manchester. Below it is an 85 MM photograph taken from the end of the Domsea Inc. dock on the south end of Bainbridge Island. It shows an area of the wood pens # 10237 that are attached to the dock as well as Pen number 12584 near Orchard Rock which appears to be a steel pen. The EPA dock and pens are visible in the distance on the right hand edge of the photo as well as Pen number 9780 behind and to the right of the red channel marker.

<u>VISIBILITY OF PENS FROM DIFFERENT LAND LOCATIONS AND ELEVATIONS AROUND RICH PASSAGE</u>: A portion of the pens were visible from almost all the locations where there is a water view in this area. At or near the shoreline (under 40' in elevation) the floating net pens are hardly visible if over 2400 lineal feet away. Within 2400 lineal feet and especially at elevations of over 40' the pens are more visible. From an elevation of approximately 90 feet and 1800 lineal feet away the Orchard Rock Pen # 12584 is visible. The photos taken 6000 feet and 10,500' feet distant were both taken at approximately 185 feet in elevation. The floating net pens are a faint line at these distances.

PROPERTY VALUES: The sales history of both improved and unimproved real estate in the Wautauga Beach area was researched. The floating net pens in Rich Passage are visible from a portion of these properties and not visible from others. A typical residence sale with a view of the pens was selected and compared to other similar residence sales in Kitsap County. I discussed the assessed values of properties in Kitsap County with Ida Mae Ryen of the Kitsap County Assessor's Office. She said the Rich Passage area was last valued in 1983 and is due for a re-evaluation next year. She indicated that they would examine every sale and check one against the other for any impacts from the pens. She also said this had been done in the last valuation and so far no differences in value have been evident.

CONCLUSION: After examining the comparable sales data from both improved and unimproved properties, some with a view of the floating net pens and others with no view of the pens, it is the opinion of this appraiser that the Rich Passage floating salmon net pens have had no effect on property values in the two plats at Wautauga Beach.

Based on observations of the floating net pens from a variety of distances and elevations it is my opinion that pens over 2400 lineal feet distant are not visible enough to have any impact on property values. At distances closer than 2400 feet they are more visible. I could not locate any closed real estate transactions of properties within this 2400 foot distance; however, there is a new home on lot 10 in the plat of Sunset Ridge on South Bainbridge Island. This home was added to the Kitsap County Tax Rolls in 1988 at an assessed value of $28,380 for the land and $94,230, for the improvements for a total of $122,610.

I located two pending sales of waterfront properties within 800 lineal feet of dock pen number 10237 and 1500 lineal feet of dock pen number 12584. The realtor who has the property listed also indicated the 430 feet of waterfront adjoining the Domsea dock and pen number 10237 was on the market. The pending sales indicate to me that the existence of floating net pens has not inhibited the development and sales of properties within 2400 lineal feet of the pens in this area.

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SALES INFORMATION

RESEARCH AREAS ON SOUTH SIDE OF RICH PASSAGE

Wautauga Beach Plat - Volume 5, Page 8, Gov't. Lot 3 & 4, NE 1/4, Sec. 9, Twp. 24W, Rge. 2E, W.M.

5200 - 5700 lineal feet to Pen No. 12584 and No. 10237

SALES ACTIVITY ON LOTS WITH NO VIEW OF THE FLOATING NET PENS.

Lot 3 and Portion of Lot 4 plus Tidelands
2-23-77 - $48,000
6-20-88 - $124,000
Home was built in 1930; 1.0 + bsmt, remodeled 1978. Lot has 100 FF WF.

Lot 10 -
10-29-74 - $3250
5-28-76 - $30,000
8-11-78 - $35,000

Lot 15 -
11-5-82 - $84,950
8-7-86 - $67,000

Lot 17 -
10-24-73 - $11,500
11-6-74 - $20,000

Lot 4 -
2-4-88 - $72,000

SALES ACTIVITY ON LOTS WITH A VIEW OF THE PENS.

Lot 42 -
4-24-81 - $100,000
10-1-87 - $92,500
Mobile home placed on property in 1975 (cost $17,495)
1974 Commodore 24' x 60'. 88.70 FT WF

Lot 31 -
1-9-79 - $60,000
7-20-87 - $81,455

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Lot 40 -
9-27-73 - $33,000
1-27-84 - $98,500
5-8-86 - $75,000
Home built 1946, remodeled 1971 and 1974 1, story.
88.70 FF WF

Lot 43
5-18-77 - $84,500
12-7-79 - $136,500
Home built 1940, remodeled 1963 and major remodel 1985-86 including swim pool, boat ramp, and marine railway

Lot 35
4-25-77 - $59,000
7-20-78 - $69,500

Lot 29
6-10-76 - $11,500
5-2-77 - $75,000

M.B. Crane's Waterfront - Addition to Manchester - Portion GL 5, Sec. 9, Twp. 24N, Rge. 2E, W.M.

- 4700 - 5500 lineal feet to Pen No. 12584 and No. 10237

ALL LOTS IN THIS PLAT HAVE A VIEW OF THE FLOATING NET PENS

Lot 5
8-8-74 - $23,500
8-28-75 - $27,500
4-12-79 - $90,000
9-26-86 - $78,000 - Divorce-property settlement
Home built in 1941, remodeled 1975 (interior) 60 FF WF

Lot 20
5-16-73 - $8,500
1-8-75 - $11,250
6-11-80 - $117,000
Home built in 1975. Lot has 62 FF WF

Lot 21
9-12-73 - $31,000
6-24-85 - $105,000
Home built in 1963, 1 story. Lot has 64 FF WF

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RESEARCH AREA ON N. SIDE OF RICH PASSAGE

HOMES WITH VIEW OF FLOATING NET PENS. PLAT OF SUNSET RIDGE, VOL. 12, PG. 74.

Approximately 1000 lineal feet to Pen No. 12227; approximately 2000 lineal feet to Pen No. 12584.

Lot 10 + Tidelands - 94 FF WF
8-27-73 - $19.250
3-22-77 - $27,000
1977 - Quit claim deed - Divorce settlement
1988 - New home on tax rolls
$122,610 assessed value.

Lot 9 + Tidelands - 97 FF WF
1985 - New home on tax rolls, $106,490 assessed value.

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REPORT - FLOATING SALMON NET PENS AND PROPOSED FLOATING SALMON NET PENS

SITE # 3: SKAGIT BAY - Skagit County, WA.
Township 34 North, Range 2E, W.M.

DATES OF INSPECTION: October 18 and 19, 1988, March 9, 1989

PURPOSE AND FUNCTION OF REPORT: The purpose of this report is to determine the effects, if any, of the existing floating salmon net pens on the surrounding upland property values. The function is to provide information useful in siting floating salmon net pens.

CERTIFICATION AND LIMITING CONDITIONS: The standard Certifications and Limiting Conditions are attached.

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AREA DESCRIPTION: Skagit Bay is located between Fidalgo Island and the north end of Whidbey Island. A portion of the bay is in Island County and a portion is in Skagit County. An existing floating salmon net pen is located in Skagit County.

Hope Island and Skagit Island are located in Skagit Bay. These two islands are both part of Deception Pass State Park.

The portion of Fidalgo Island bordering Skagit Bay on the east is part of the Swinomish Indian Reservation. The reservation in this area has a combination of lands in fee ownership, lands leased by the tribe and tribal owned lands. All tidelands are claimed by the tribe.

Residential development in this area of the Swinomish Indian Reservation is mainly along the waterfront. The terrain here is a gradual slope from beach level to about 300 feet in elevation one-half mile inland.

Whidbey Island on the west side of Skagit Bay is a combination of private ownership and Washington State Park ownership. The portion in private ownership is sparsely populated due to the steep terrain along the water.

The interior of both the Swinomish Indian Reservation and the north end of Whidley Island are largely undeveloped.

Skagit Bay has an existing floating salmon net pen complex approximately 1800 lineal feet north of Hope Island and 1200 lineal feet west of the Lone Tree Point. According to information supplied by the Skagit Systems Cooperative, installation of these pens was begun in May of 1987.

SIZE AND DESCRIPTION OF EXISTING FLOATING SALMON NET PENS: The existing floating salmon net pen lease # 12356 is approximately 100 feet by 480 feet and according to the Department of Natural Resources lease covers .66 acres of water surface.

The pens appear to be of steel construction when viewed from the shore. There is a supply building, 10 feet by 20 feet by 10 feet high, at the pen site as shown in the photo exhibit.

LOCATION AND DESCRIPTION OF PROPOSED FLOATING SALMON NET PENS: The Skagit System Cooperative is proposing to locate a 100 foot by 480 foot complex of floating salmon net pens about 1800 lineal feet southeast of Hope Island and 4400 lineal feet due west of Sunset Drive, a street in the Plat of Wagner's Hope Island Addition. These pens will be about 7400 lineal feet from the closest point on Whidbey Island and about 3100 feet southwest of Snee-oosh Point, the nearest land on Fidalgo Island. The pens are to be steel construction similar to the steel pens shown in the lower left hand corner of the Rich Passage exhibit. A small building, 10 feet by 25 feet by 10 feet high, will be located at the site of the pens to provide protection for the employees and limited storage of food.

VISIBILITY OF PENS FROM DIFFERENT LAND LOCATIONS AND ELEVATIONS AROUND SKAGIT BAY: Photographs (50 MM) were taken from different areas as shown on the Anacortes South quadrangle map exhibit. These areas were visited and photos taken of the proposed location of a new fish pen complex and the existing fish pens. Approximate distances from the pens and elevations at the site are noted near each picture.

PROPERTY VALUES: Sales of unimproved and improved real estate along the east shore of Skagit Bay were researched for the period of 1986, 1987, 1988 and 1989. Two recent sales of homes with a view of the existing net pens have recently been recorded and a third sale is scheduled to close on April 10, 1989. It is my opinion that these homes sold at Fair Market Value.

CONCLUSION: The Skagit Bay area is presently providing the best information on property values as sales are recorded on homes less than one mile from an existing salmon net pen complex.

Sales data from the area indicates that two homes with a view of the pens were recently sold at Fair Market Value. These homes are approximately 3000 and 3900 feet from the pen site.

There are several new homes under construction south of Snee-oosh Point. These homes will be approximately 4100 lineal feet east of the approved proposed pen complex.

After examining the comparable sales data from areas without a view of the pens and the construction activity in the area of the approved new pen site, it is the opinion of this appraiser that the Skagit Bay existing floating net pens and proposed floating net pens have not affected property values in this area as as indicated by the recent market sales of homes at 1606 Snee-oosh Road and 1575 Snee-oosh Road.

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SALES INFORMATION

RESEARCH AREAS ON SKAGIT BAY - SW SIDE OF FIDALGO ISLAND

WAGNERS HOPE ISLAND ADDITION

Lot 6 & N. 20' of Lot 5, Bl. 4 (1740 Golden View Dr.)
4/86 - $120,000, Residence built 1958

Lot 3, Bl. 3 (1732 Golden View Dr.)
11/86 - $130,000, Residence built 1963

Lot 2 and Ptn. Lot 1, Bl.4 (1746 Golden View Dr.)
5/88 - $85,000, Residence built 1969

FAHLENS SNEE-OOSH TRACTS
Lot 4 (1668 Reef Point)
8/86 - $178,500, Residence built 1969

PLAT OF SNEE-OOSH
Lot 65 (712 Chilberg Ave.)
7/86 - $115,000, Residence built 1927

PLAT OF SHOREWOOD
Lot 9
1/87 - $42,500, Unimproved lot

PORTION OF GOV'T. LOT 1, Sec. 27, Twp. 34N, Rge. 2E, W.M.
1606 Snee-oosh Road
10/6/88 - $284,000, Residence built 1979

PORTION OF GOV'T. LOT 1, Sec. 22, Twp. 34N, Rge. 2E, W.M.
1575 Snee-oosh Road
10/6/88 - $73,500, Residence built 1967

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RESEARCH AREA SIMILK BAY - FIDALGO ISLAND

SIMILK BEACH PLAT
Lot 23 & Ptn. Lot 24, Bl. 6 (624 Satterlee Rd.)
8/88 - $61,000, Residence built 1920

GIBRALTER AREA
Ptn. G.L. 6 Sec. 19, Twp. 34, Rge. 2E (500 Gibralter)
8/88 - $120,000, Residence built 1973

RESEARCH AREA SHELTER BAY - SE. SIDE OF FIDALGO ISLAND

SHELTER BAY PLAT
Lot 743, Shelter Bay #4 (743 Tillamuk Dr.)
8/88 - $130,000, Residence built 1972

Lot 457, Shelter Bay #3 (457 Klickitat Dr.)
8/88 - $123,000, Residence built 1973

RESEARCH AREA SKYLINE - FIDALGO ISLAND

SKYLINE PLAT
Lot 85, Div. 8 (5104 Kingsway)
7/88 - $98,700, Residence built 1970

Lot 41, Div. 11 (2205 Dover Drive)
7/88 - $125,000, Residence built 1980

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REPORT - FLOATING SALMON NET PENS

SITE #3: DISCOVERY BAY - Clallam County, WA.
Township 30 North, Range 2W, W.M.

DATES OF INSPECTION: August 19 & 20, 1988

PURPOSE AND FUNCTION OF REPORT: To compare Discovery Bay with Peale Passage and Rich Passage. The function is to provide information useful in siting floating salmon net pens.

CERTIFICATION AND LIMITING CONDITIONS: The Standard Certifications and Limiting Conditions are attached.

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AREA DESCRIPTION: Discovery Bay is a large bay situated between the Miller Peninsula and the Quimper Peninsula. A portion of the bay is located in Jefferson County and a portion is in Clallam County. The portion of the bay where the proposed floating salmon net pens are located is in Clallam County.

Discovery Bay and Rich Passage are similar with areas of fairly dense development, areas of scattered homes along the waterfront, and some unimproved properties. Peale Passage is relatively undeveloped by comparison with only 4 or 5 areas where groups of waterfront homes are clustered near the end of a road.

TOPOGRAPHICAL INFORMATION: Discovery Bay has a much wider variety of terrain than either Peale Passage or Rich Passage. Discovery Bay has several no bank waterfront areas such as Diamond Point, Beckett Point, and Gardiner. It also has many medium to high bank areas. Elevations near the waterfront range from 11' to 600' feet above sea level.

SIZE AND DESCRIPTON OF PENS: It is my understanding that the proposed Discovery Bay pens will eventually be 100 feet by 1000 feet in area and are to be steel pens.

I do not know what materials were used in constructing the Peale Passage Pens as they were not visible from any of the areas I visited. The Rich Passage pens are constructed from a variety of materials. Some were wood, others a combination of wood and steel, and others were steel.

VISIBILITY OF PENS FROM DIFFERENT LAND LOCATIONS AND ELEVATIONS AROUND DISCOVERY BAY: Photographs (50 MM) were taken from different areas as shown on the attached Gardiner quadrangle map exhibit. These areas were visited and photos taken of the proposed fish pen location to make comparisons with the other areas visited. Approximate distances from the proposed pens and elevations at the site are noted near each picture.

CONCLUSION: After visiting all three study areas and evaluating the information gathered in the field it is my opinion that areas over 2400 lineal feet from the floating net pens will have little visual impact and their property values will not be adversely affected. Residential areas less than 2400 lineal feet from the pens will have some visual impact.

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In Peale Passage and Rich Passage floating net pens were originally located in areas with no residential development within 2400 feet of the pens. In the past 3 years two new waterfront homes with a view of the floating net pens were built on the north side of Rich Passage and several waterfront parcels adjoining the Domsea Dock and Pens in this same area are in the process of being developed and sold. Because of the lack of sales history for properties within this distance it is not possible to make any direct value comparisons, however, the building and development activity in the area indicates the impacts have been minimal. This is consistent with my personal experience as a real estate appraiser. Over the past 8 years, I have appraised many waterfront and water view properties in Jefferson and Clallam Counties. I have found that waterfront and marine activities do not adversely affect upland and waterfront property values.

APPENDIX L

ECONOMIC ASPECTS OF SALMON AQUACULTURE

The Northwest Environmental Journal, 5:37–52, 1989
University of Washington, Seattle, Washington 98195

Economic Aspects of Salmon Aquaculture

James A. Crutchfield[1]

Scope and Purpose

Aquaculture, broadly defined, includes shellfish culture, ocean ranching (i.e., the hatchery production of selected stocks which are released to the ocean and harvested upon their return), and pen-rearing of various species of finfish. This paper focuses on the explosive and controversial growth in farming of salmon. Pen-rearing of salmon is definitely where the action and the emotions are centered in Washington State, although controversy also has arisen over the proposed rearing of edible seaweed (nori) and the expansion of shellfish culture.

The policy issues involved in the disputes over pen-rearing in Washington waters tend to be viewed as regional, but it is impossible to assess them without considering similar issues elsewhere in the world. Our local expertise and capital are drawn, in part, from abroad, and farmed salmon now are standardized items in world trade.

The first part of this paper deals with the development and current economic situation of salmon farming in the broader setting. The second part discusses the potential role of Washington State in the global market and a number of factors that give rise to some peculiarly local problems. The term *Puget Sound* is used throughout to mean the area from the Canadian border, south to Clallam County on the Strait of Juan de Fuca.

World Salmon Farming: The Norwegian Experience

Pen-rearing is hardly a new toy in the fisheries world. Sophisticated pond culture has been carried on in China and Southeast Asia for centuries, and there are active brackish-water rearing enclosures in Gaeta, Italy, which once served the elite of Roman society. Experimental and modest commercial production of pen-reared salmon goes back to the 1970s. Indeed, much of the best research on

[1] Professor Emeritus, Department of Economics, Graduate School of Public Affairs, and Institute for Marine Studies, % Institute for Marine Studies (HF-05), University of Washington, Seattle, Washington 98195.

rearing of salmonids has been carried on in Washington State for decades by scientists at the University of Washington and the National Marine Fisheries Service. Nevertheless, large-scale commercial production under controlled conditions is a relatively new development. Catfish in the United States, yellowtail and shrimp in Japan, and shrimp in Latin America now support solidly established industries. But nothing matches the excitement and the economic impact of the explosive growth of pen-reared salmon, which followed years of limited success and experimentation in Washington, British Columbia, Chile, and elsewhere.

Pacific salmon (coho and chinook) remain the mainstay of pen operations in Japan, British Columbia, Chile, New Zealand, and the state of Washington. In a dozen years, the output of farmed coho in Japan has risen to an estimated 15,000 metric tons (mt); Atkinson (1987) has forecast production of 30,000 mt by 1990. British Columbia operations also are based largely on coho and chinook, and have grown very rapidly with relaxation of tight government restrictions. Between 125 and 160 licensed farms presently are active. New Zealand's farms are devoted to chinook, and Washington State's pen-rearing operations are producing coho and a small quantity of chinook.

Except for Japan, however, change is in the wind. Washington's largest coho farm was sold recently to Norwegian interests and will shift to Atlantic salmon; all of the applications for permits now before the State are for Atlantics. Recent investments in Chile and British Columbia by large European multinationals also will be devoted to that species. Japanese firms, on the other hand, continue to concentrate on coho in both production and imports, although some New Zealand chinooks and Norwegian Atlantics are now found in Japanese markets. At present, Atlantic salmon account for about 78 percent of world production.

As might be expected in this fluid situation, estimates of total world production of pen-reared Atlantic and Pacific salmon from different sources vary widely. The current forecast figures in Table 1 are believed to be reasonably reliable. All sources share a common theme, however: Very large increases in the supply of pen-reared salmon will reach U.S., European, and Japanese markets in the next few years.

The real breakthroughs in rearing Atlantic salmon came first in Norway, where a strong government program of research and development grew out of the need for new economic opportunities in the depressed coastal fishing areas. Table 2 tells a tale of almost uninterrupted success. From a meager 3,500 metric tons in 1978, production is projected at nearly 80,000 tons in 1989, and—barring unexpected problems—is expected to exceed 100,000 tons by 1990. This spectacular record has not been without its bumps and chuckholes, however. The industry struggled in its early years to meet color and size requirements for its dominant European market. In 1985, a temporary decline in prices caused some concern. In 1986 and 1987, production was curtailed by an outbreak of disease. In 1988, a massive onset of growth of algae required physical removal of many pens in Norway; though few fish were lost, the cost of moving them out of danger was substantial. Scotland also has suffered from algae blooms in recent years.

The success of the Norwegians in pen-rearing Atlantic salmon was not happenstance; it resulted from a combination of excellent natural endowments, supportive government policy, and an energetic and well-organized industry (Lavin-Riely and Anderson 1986). Atlantic salmon can be "grown out" in pens from smolt to desirable market size (2–6 kg) in about 18 to 24 months, and are less susceptible to disease than Pacific species. Despite general depletion of Atlantic salmon after World War II, Norway had a fairly good supply of genetically-diverse wild stocks from which to draw. Its long coastline provided excellent water temperature regimes and an abun-

TABLE 1. World production of Atlantic and Pacific salmon (in metric tons), 1987–1990.

Salmon	Country	1987	1988	1989[2]	1990[2]
Atlantic	Canada	800	1,600	3,200	5,000
	Faroe Islands	4,800	4,800	7,100	9,000
	Iceland	800	1,800	2,500	5,000
	Ireland	2,200	4,500	6,600	10,100
	Norway[1]	53,000	80,000	84,000	107,000
	England	13,900	15,000	20,000	25,000
	United States	800	1,700	3,200	5,200
	Sub-total	76,300	109,400	139,400	166,300
Pacific	Canada	3,200	8,400	14,600	23,000
	Chile[1]	1,700	3,500	15,400	17,000
	Japan[1]	13,000	15,000	17,000	30,000
	New Zealand	1,000	1,500	2,000	3,000
	United States	1,700	2,000	2,400	2,500
	Sub-total	20,600	30,400	51,400	75,500
Total		96,900	139,800	190,800	241,800

[1] Figures for Norway, Japan, and Chile have been adjusted on the basis of more recent reports.

Source: Cited in Anderson 1987. Norway continues to expand [from a report by JETRO quoting data by National Marine Fisheries Service (NMFS)]. Suisan Tsushin, Tokyo. November 11, 1988. (Printed in Japanese.)

[2] Projected by above JETRO report quoting NMFS data.

TABLE 2. Supply of farmed Atlantic salmon: Norway and other countries (in metric tons), 1978–1990.

Year	Other countries	Norway	Total	Percent of total
1978	250	3,500	3,750	93.0
1979	470	4,150	5,598	89.9
1980	1,445	4,153	5,598	74.2
1981	1,133	8,422	9,555	88.1
1982	3,527	10,265	13,792	74.4
1983	2,839	17,016	19,855	85.7
1984	4,552	22,300	26,852	83.1
1985	6,500	28,655	35,155	81.5
1986	10,600	38,000	48,600	78.2
1987	14,700	50,000	64,700	77.3
1988	N/A	80,000	98,000	
1989*				
1990*	40,000	107,000	147,000	72.8

Source: The University of Stirling Institute for Retail Studies Market Reports, Volume No. 2, pp. 42, 43. 1988 and 1990 estimates from trade sources.
* Projected by the University of Stirling Institute for Retail Studies.

dance of sites relatively free of pollution. There was little public opposition to this new water use. Government aids, in the form of scientific research, capital funds, subsidies, and quality control, were used effectively. The industry rapidly developed marketing and production strategies that made year-round supplies of high-quality fresh salmon widely available. Even if account is taken of the subsidies, salmon farming has proved highly attractive to Norwegian investors. When 150 new permits were made available recently, there were more than 1,500 eager applicants.

The World Joins In

The boom has become international, although Norway's share of the total production of Atlantic salmon was still over 70 percent in 1987 (Table 2). The United Kingdom, Canada, Chile, Japan, Iceland, Ireland, New Zealand, and the United States—together with five other nations, several of them long active at low levels—now are expanding production rapidly.

In addition, substantial quantities of farmed salmon may reach U.S. and European consumers from small "pockets" of good rearing sites that are favorably located near transportation and markets. For example, New Brunswick is producing Atlantic salmon for sale in the U.S. and is reported to have the potential for as much as 10,000 tons annually. Substantial quantities may be forthcoming from sheltered areas in Maine. The British Columbia Ministry of Agriculture and Fisheries estimates that there are more than 700 potential sites in British Columbia alone (DPA 1986).

The "internationalization" of salmon farming certainly would have occurred as a result of market forces alone. Another factor was the availability of suitable sites in many parts of the world. But the process has been accelerated by Norwegian fishery policies. (For an excellent summary of these policies, see Bjorndal 1988.) Briefly stated, the government's approach to the new pen-rearing industry has been dominated by two goals: (1) to place farms in regions with limited employment opportunities (perhaps resulting in less migration to large urban areas); and (2) to gear the pace of production to growth in the market for pen-reared fish and, thus, stabilize prices at profitable levels. These objectives were reflected in tight restrictions on the number of smolt-rearing and feed-out farms (where hatchery-raised smolts that have been moved to rearing pens—usually in natural saltwater—are fed in the pens); limitations on farm size and multiple-site ownership; and insistence on industry-wide pricing, quality control, and the provision of genetically-strong eggs and smolt. The government also has subsidized the development of a multi-mode transportation system linking fish farms and their suppliers (Mylchreest 1985).

These policies have, in general, achieved their goals, but they also spurred the export of Norwegian capital and expertise to other countries. Experience and technological progress brought an awareness that government restrictions were preventing the realization of economies of scale in the size of individual farms, operation of multiple sites, and vertical integration of smolt production, feed-out, processing, and marketing. Many of Norway's farms are smaller than the allowable 8,000 cubic meters. (The Norwegian government authorized a 12,000-cubic-meter limit but as of this writing, it has not been implemented.) Several studies (e.g., Bjorndal 1988; Salvanes 1986) indicate that operations several times that size would probably bring important reductions in unit costs. This, coupled with the sobering realization that Norwegian salmon farmers would soon feel the pinch of stabilizing prices and increased foreign competition, lead to a continuing effort to bring Norwegian skills and capital to locations free of these restrictions. In the U.S., Canada, Chile, Scotland, and elsewhere, the dominant factor in salmon farming has been the Norwegian presence. (For an excellent summary of Norwegian investment activity in the U.S. and Canada, see Parker 1988.)

Norway provides an example of establishing quality controls through a central agency (the Fish Farmers Sales Organization), backed by government inspection and export certification. This example has been followed, through government or industry action, by all major producing countries except the United States (Ringstad 1986). Given the reliance on high and consistent quality as a device for market penetration, this type of control probably is essential to prevent "free-riding" by less scrupulous producers and marketers. In short, the U.S. development of pen-rearing potential must be accompanied by measures to assure industry-wide adherence to high quality standards.

Markets

The phenomenal growth in farmed salmon production raises the two obvious questions of where it is going and how markets can absorb such quantities.

The markets for salmon are highly segmented. The major markets (U.S., Japan, United Kingdom, Germany, and France) distinguish wild from farmed salmon; coho, chinook, and sockeye from Atlantic; troll-caught from net-caught Pacific fish; fresh from frozen; and small from large fish. Cross-elasticities of demand (i.e., the sensitivity of demand in one segment to changes in prices in another) are not identical, but are linked to some degree. Thus far, farmed salmon have fitted into the markets for salmon by building new demand for fresh fish "out of season," and by edging into the European smoked salmon markets traditionally served by wild fish or U.S. frozen fish. There is, contrary to one widely expressed view by salmon farmers, both direct and indirect competition with wild fish, but farmed salmon clearly are making up the growth component.

The "white tablecloth" restaurants are by far the most important outlets for quality fresh salmon, and it is in this segment of the market that farmed fish offer their greatest appeal. Restaurants cannot afford to promote a high-priced item like salmon without a guarantee of consistent supply. Unlike troll-caught chinook and coho, farmed Atlantics are available in uniform sizes, quantities, and guaranteed freshness year-round. In particular, they fill the long gap left by the highly-seasonal availability of wild salmon.

For the busy restaurateur, the ability to order by telephone to meet exact needs, rather than touring fish markets to examine individual lots, is an attractive feature that reduces costs and increases menu flexibility.

Uniformity of size and quality, and steady supply also may be the principal characteristics that make farmed salmon a prime candidate

for sale in the imaginative plastic packaging developed for use in retail chains and supermarkets.

From the standpoint of the important European salmon-smoking industry, the ability to buy raw materials, as needed, significantly reduces holding costs (i.e., storage, freezer capacity, quality maintenance, and interest charges).

Note the emphasis on continuity of supply of market-sized fish, a problem never completely solved in efforts to build a strong market for pen-reared coho. Few farm operations, even with multiple sites, can deliver farmed Atlantic salmon in fresh form through a full year, but the growing diversity of sources in both northern and southern hemispheres means that the entire market can very nearly meet that goal. Skillful use of the freezer, and care in subsequent handling, can bridge the remaining gap. For obvious reasons, marketing of farmed fish is heaviest in the eight months when fresh wild salmon are scarce or unavailable. It also should be noted that some of the coho production is marketed at pan-size and competes with trout rather than other fresh salmon.

In short, the growth in sales of farmed salmon to date reflects a number of real marketing advantages over wild fish in the high quality fresh-fish-oriented segments in which they have concentrated. The ability to maintain a high growth rate, however, will require much broader penetration, probably with a wider variety of end products. With wild salmon landings holding fairly steady at around 650,000 mt, farmed salmon will account for about 14 percent of total supply by 1990. The figure is much higher for wild Atlantics, Pacific chinook, and coho—the three species which compete most directly. There is a big marketing job to be done in the near future.

Industry Structure

The basic structure of salmon farming is essentially that of a marine feedlot operation. Selected salmon eggs are reared in a hatchery and raised to smolts of 35–50 g in a second stage. The smolts then are moved to rearing pens, usually in natural saltwater environments, and grown to marketable size (about 2–6 kg). The fish are harvested and bled on site for transportation to processors and then are frozen or shipped by air or truck to export destinations. Subsequent distribution in the United States is handled through established fresh-fish marketing channels, with a small quantity sold in frozen form. A rough estimate of price relationships in the U.S. at various states in the process is shown in Table 3.

TABLE 3. Cost structure for fresh farmed salmon from Norway, in dollars (USD).

	USD
Price FOB Norway	6.56/kg
Air freight ex Norway	1.74
Margin of importer (7%-10%)	0.83
Selling price of importer	9.13
Overland freight	0.22
Margin of wholesaler (20%)	1.87
Selling price to restaurant	11.22

Source: Ringstad 1986.

Biochemical Problems

The industry has struggled in its early phases with a number of economic problems. Smolt production has been carried on as a separate operation in most cases, and often has fallen short of demand from the rapidly growing farm operations. The scramble for smolts has, in turn, added to the problem of straying of escaped farm fish and genetic disruption of wild salmon stocks on which the Norwegian industry is still dependent. Briefly, this results from mixing of wild and farmed fish and the subsequent dilution of the complex set of genetic characteristics that tailor each wild stock to the specific conditions of its river of origin. In Norway these problems have been addressed by a centralized governmental research program to develop brood stocks of appropriate diversity, as well as by careful control of imports. These are inherent problems that must be addressed, by public or combined industry action, in any salmon farming area. In Washington State the permitting process requires careful attention to the potential impact of salmon farmers on wild and hatchery stocks.

A major factor affecting costs of pen-rearing is the need to control disease and to improve survival rates. Like any other marine animal, diseases become more troublesome as stocking density increases. Drug treatment is expensive and raises questions about transfer of potentially toxic material to other marine organisms or to human consumers. In Norway, the higher incidence of disease in older fish has at times restricted the size to which salmon can be grown; this runs counter to market preference for larger fish.

There is always the risk of adverse developments in the complex marine environment on which pen-rearing depends. Changes in salinity, temperature, algae blooms, and food web relations (not to mention oil spills, waste disposal, and other human insults) pose contingent threats to salmon farms.

Some of these threats will doubtless be reduced by the sheer pressure of the marketplace, but always at some additional cost to producers. And the number of unknown and uncontrollable loss factors will remain large enough to make pen-rearing a high risk business.

Finally, the availability of high quality feed has been a recurrent worry, particularly in newly developed salmon farming regions. The fish meal industry is geared to a huge demand for poultry and animal feeds, which are not suitable for fish. In the intermediate term, improved knowledge of nutritional requirements at each stage of development (from egg to mature salmon) and the growth in the size of the market for salmon feed will provide the market incentives to meet the problem; in the interim, however, it remains an important concern in some areas.

The Trend Toward Concentration

It is not surprising that these unresolved biotechnical problems, together with better access to capital and markets, have tended to push the salmon-farming industry toward fewer and larger units, better able to reduce risks through multiple-site operations and to tie successive input requirements (eggs, smolts, and feed) to controlled sources through vertical integration. This trend has been impeded by Norway's regulatory orientation, but is clearly evident in other countries such as Canada, Scotland, and Chile. A study of British Columbia farms showed that about 60 percent of their production came from 15 percent of the farms (DPA 1986).

Geographic decentralization of the industry will doubtless continue, not only because of Norway's restrictive policies, but also because of high transport costs. Air freight to the U.S. from Norway averages about $1.74/kg and up, which provides a substantial umbrella for farmers located closer to consuming centers. Chilean fish are brought to the West Coast by one large U.S. firm in chartered Boeing 707s—an outlay that can only be absorbed because of southern Chile's low wages and freedom from controversy about environmental problems. Canada, of course, has a clear advantage with respect to transportation to U.S. markets.

Salmon Farming in Washington State

Why has Washington been so slow in joining the pen-rearing boom? Washington has had some early experience in farming coho salmon—some of it marginally successful and some disastrous. A great deal of sophisticated and practical research in rearing of salmonids has been carried on by the University of Washington and the National Marine Fisheries Service. The state's potential sites have been investigated, largely by technically competent domestic and Norwegian interests. Yet only 7-13 marine rearing operations now are believed active, compared to some 125-160 in British Columbia.

Proponents of aquaculture are quick to point a finger at the slow pace of governmental site certification and the failure of the state to provide firm guidelines for site approval and farm operation. There is some measure of truth in their position. For example, there are definite conflicts between state agencies and local governments that must be resolved. The concerned agencies—the Governor's office and the departments of Agriculture, Fisheries, and Natural Resources—are strong supporters of rapid expansion of aquaculture. Local governments are more exposed to the direct heat of constituents who are concerned about negative effects and are generally opposed to anything more than token pen-rearing. They argue, again with considerable justification, that they pay most of the external costs and assume all of the environmental risks of salmon farming with extremely small economic benefits (see "Economic Non-Issues," below). Coalitions of opposition groups originating at the country level have become increasingly vocal at the state and local levels.

It seems clear that the cautious attitude of the state government toward action, as opposed to rhetoric, is a response to real public concerns about the impact of a large pen-rearing industry on local areas and on the state as a whole. Weston's studies (1987) and experience in Norway confirm the likelihood of water quality degradation in limited areas from fecal matter and unused feed. But how extensive or persistent these effects may be, particularly after long periods of operation, remains an open question which can only be answered on a site-by-site basis. If, for example, it turns out that the pens must be moved every few years, the unpleasant possibility emerges of continuous struggles over certification of new sites.

I am not qualified to assess the significance of other biological impacts, e.g., transmission of diseases to native fish stocks, straying and genetic damage, long-term effects of drugs and other chemicals on local biota and/or humans, and possible damage to birds or marine mammals. While it seems likely that the probability of catastrophic damage is small, the probability of zero damage is even smaller. Whatever their level, biological impacts mean increased social costs—some that can be measured in dollars, others that cannot.

Probably the most important negative impact is the degradation

of scenic values for shoreline and upland property owners, and restrictions on quality water-based recreational activities, particularly boating. Unfortunately, there is no operative price mechanism which would help establish a schedule of best uses for these waters. But the losses are certainly very real to those directly affected, as evidenced by the widespread opposition that has developed in the greater Puget Sound region. Regional environmental quality is a composite of many things, and it is vulnerable to the "nibbling" process that accompanies growth in population and industry. Moreover, environmental losses are all-too-frequently irreversible.

It must be stressed that Puget Sound already is an intensively utilized land/water system. Water transportation, commercial and recreational fishermen, pleasure boaters, beachcombers, and shoreline residents all compete in varying degrees for use of these waters. Virtually all of the desirable pen-rearing sites will put salmon farmers in direct conflict with some other users.

Unlike other major sea-farming areas, e.g., the west coast of Norway, Scotland's north coast and islands, and southern Chile, there is no logical argument that salmon *farming* is needed in isolated areas of Puget Sound where unemployment and labor immobility create serious social problems. The Puget Sound region is the most prosperous in the state, and even the distressing condition of the commercial salmon fishery is largely offset by the ready availability of off-season employment. For most commercial fishermen, Washington offers a variety of better jobs than unskilled manual labor on salmon pens.

Economic Non-Issues

The real issues in the controversies over site approvals have been obscured by a number of economically faulty arguments put forth by both sides. For example, proponents repeatedly have claimed that a fully-developed Puget Sound salmon-rearing industry would reduce the nation's serious international balance-of-payment problems. But in recent years, *total* salmon imports to the United States amounted to less than one-tenth of one percent of the $150 billion deficit in the U.S. balance of trade.

The promise of major increases in jobs and entrepreneurial opportunities is equally suspect. A recent study by the State Department of Trade and Economic Development (Inveen 1987) suggests that primary employment in a typical Puget Sound pen-rearing operation would be eight to ten persons, with an average annual wage of about $19,000—ranging from $14,500, to $30,000 for the manager. Capital investment required would be about $750,000-

$1,000,000, and annual operating expenses about $1,400,000 (feed, 30 percent; labor, 14 percent; smolt, 12 percent; "other," 44 percent). Assuming eight additional jobs in secondary activities, the total increase in employment from ten new salmon farms would be about 160–200, and the number of new firms would be something less than ten: These are useful additions, to be sure, but not of major significance. These figures are consistent with estimates of labor inputs in the Norwegian industry (Bjorndal 1988).

On the other side of the controversy, commercial fishermen have resolutely opposed any increase in salmon farming for two reasons: (1) the encroachment on fishing grounds or areas in which fish are transferred to buyers (where boats anchor during closed periods); and (2) the adverse effects of farmed fish on market prices. The first point is a legitimate one, but it could be met by identifying and blocking out areas where pen-rearing activity would impact traditional fishing activities. This would, however, further restrict the number of sites that meet state guidelines.

The second point is more complex. Two questions are raised: Would farmed fish actually compete with wild fish in the market? If so, should traditional harvesters be shielded from such competition? To some extent competition in the fresh market is limited by timing. Wild salmon are available in fresh form only during a "window" of about four months (and for Washington trollers and net fishermen, the window is even narrower); imports of farmed fish are heavier in the off-season. The boundaries are not that neat, however. Atlantic salmon can be found on restaurant menus year-round, particularly in East Coast and Midwest markets. High quality frozen wild fish, which normally filled the winter/spring gap, are directly competitive with farmed fish. If, as trade journals suggest, more and more farmed salmon will be frozen as production expands, competition with wild fish will broaden (*Seafood Leader* 1988).

Pen-reared coho, in smaller sizes, are considered more comparable to farmed trout. Larger coho from Chile, however, are close substitutes for wild fish, as are chinooks from farms in New Zealand and British Columbia.

In aggregate terms, it is difficult to avoid the conclusion that farmed salmon must either moderate price increases or actually cut real prices for domestically-harvested wild salmon. Imports are much greater than the supplies of troll-caught chinooks and coho, which are most nearly comparable in quality.

A recent study (Rogness and Lin 1986) offers partial confirmation of this conclusion. Seventy-nine percent of the wholesalers and distributors responding to their survey felt that fresh farmed Atlantics were a direct substitute for fresh Pacific fish. A smaller portion (26 percent) felt that frozen farmed Atlantics compete directly with frozen Pacifics, but this may change as more and more imports come in frozen form from sources such as Chile and New Zealand.

There is general agreement that exports of wild salmon to Europe (about 10-15 percent, by value, of total U.S. production) will feel the impact of farmed salmon most severely. European smokers, traditionally the major purchasers of frozen troll-caught chinook and coho, have turned increasingly to Norwegian, Scottish, and Irish farmed Atlantics. (This comment is based on an unpublished paper, "International Salmon Farming: Competition for U.S. Fishermen?" by Stephen M. White for a fall 1986 class at the Institute for Marine Studies, University of Washington, Seattle.)

For obvious reasons, the impact of farmed salmon on prices and market shares for traditional fishermen is critically dependent on the long-run breadth and depth of the overall market for salmon. There is probably some validity to the aquaculturists' position that year-round availability of salmon will boost demand for both farmed and wild fish in both restaurant and retail markets. The excellent job of quality control by marketers of farmed salmon may force badly needed improvements in the handling of wild salmon, which would add further strength. But a major, concerted promotional effort will be required if forecasts of 200,000–300,000 tons of farmed salmon annually come to pass and the estimated minimum wholesale prices of $3.50–$3.75 per pound are to be maintained.

From the standpoint of Washington State policy, perhaps the best response to the competition question is: So what? Consumer preferences ultimately determine the relative place of different salmon products in different markets, with price differentials serving as the allocative mechanism. This is the way private enterprise economies are supposed to work. Any effort to stifle production of a new or better product for the benefit of an existing segment of industry runs directly counter to the rules of the game, and would be doomed to failure in time. Moreover, the additional output of Washington farmed salmon, even under the rosiest assumptions, would have little or no measurable effect on prices that are determined by worldwide supply and demand.

Conclusions and a Look Forward

We conclude with words about roses and the thorns that go with them. First the good news:

1) If market limitations do not intrude, there are ample areas for expansion of the physical production of salmon farming, even in

Norway where 700 pen-rearing operations are licensed. Chile, British Columbia, and—if political opposition is overcome—Alaska have hundreds of potential sites with suitable water and temperature conditions and little or no competition for land or water. Others with growth potential include New Zealand, Ireland, Scotland, Iceland, the Faeroe Islands (Denmark), and a few areas in New England and the Canadian maritime provinces.

2) Neither technical expertise nor capital appear to be limiting factors over time. The former can be purchased, and the latter is readily available from Norway and, increasingly, from multinational corporations (e.g., Unilever and British Petroleum).

3) Thus far, the export marketers of farmed salmon have concentrated on dressed and whole fish in fresh form. New profit opportunities for exploitation of new consumer portions, preparations, and packaging have barely been touched. In addition to broader consumer appeal, these developments will integrate the marketing of farmed fish that have established food marketing channels, with substantial savings in distribution costs. (The same avenues for improvement are also available to wild fish, of course.)

4) Shellfish culture and shrimp, salmon, and catfish rearing are by no means the end of the road for commercial aquaculture. Experimental work is underway in controlled rearing of a variety of other popular species—cod, halibut, sturgeon, Arctic char, and turbot, to mention only a few (Lavin-Riely and Anderson 1986). We are far from the situation in animal husbandry, where centuries of research, genetic modification, and field testing have identified the most promising species and further modified them for human use. Given the ubiquitous world need for more protein foods, there is every reason to believe that frontiers in the cultivation of marine animals will be pushed hard.

Now for the thorns:

1) The trade literature reflects widespread uneasiness about the timing and effect of the inevitable industry stabilization process. Markets do not expand indefinitely. As farmed salmon fill out their present niches in the fish (and wider animal protein) markets, the relatively stable premium prices enjoyed since 1984 by farmers and distributors must soften, if production continues its headlong growth. This "overrun" phenomenon, typical of new industries, may be deferred and its impact softened if new and much larger consumer groups can be reached (e.g., if high-volume chain retailers begin to push farmed salmon after only moderate declines in real prices). If not, a painful shakeout period of considerably lower prices and bankruptcies can be expected. This period could be quite pro-

tracted, due to the long production cycle for salmon (Bjorndal 1988; Ringstad 1986). Anderson (1988), in a recent analysis of demand for farmed salmon, indicates that a supply of 125,000 mt could be moved *only at prices about 20 percent below present levels.*

2) Salmon farmers in some areas are beginning to feel the pinch as some previously "external" costs begin to fall on their shoulders. These include, for example, the increasing incidence of local pollution, which requires more stringent controls by the operators and, in some cases, shifts in location. Adverse effects of some of the most effective chemicals used to control disease and to retard fouling of pens may require use of less potent substitutes or location shifts. Governments cannot reasonably be expected to subsidize the industry indefinitely; eventually aquaculture must begin to contribute to the necessary costs of research and management, and to pay full costs for all inputs.

3) The combined effect of stable real prices and rising costs already has begun to cause concern about the financial condition of many marginal firms, even in Norway (Bjorndal 1988; Ringstad 1986). This has accelerated the search for new, low-cost production sites and will strengthen the move toward larger, integrated firms and the linkage of fish farming to conglomerate international corporations.

4) Expansion of salmon farming in some areas (e.g., Washington) has met determined opposition from property owners adjacent to the proposed pen sites, commercial fishermen, and some environmental groups. This resistance can be expected to continue, and probably will prevent more than limited growth in areas close to major markets. Obviously, if the concerns about adverse environmental effects turn out to be warranted, the restrictive pressure will become much stronger.

From the standpoint of *all* residents of the Puget Sound region, there seems to be no reason to rush headlong into pen-rearing. Fitting salmon farms into a heavily populated area with a wide array of water-dependent industries, recreational users, and shoreside home owners will be a ticklish task. It will demand full public review and evaluation of the state environmental impact statement, and detailed analysis of site-specific factors involved in each application. Salmon farming is a legitimate claimant on Washington inshore waters, but it is only one of many. There is no apparent reason why it should be given special priority.

This cautious approach, essential if Puget Sound is to yield its greatest overall economic and social benefits, may delay the entrance of Washington producers into the market. But what is lost? The market will still be there and, hopefully, growing. Farmed salmon is an undifferentiated product, and no supplier is going to seal off the market to new entrants. If Washington producers can meet prices and quality standards of imported fish, they will sell readily. As indicated above, the industry expects a fairly severe shakeout period in the early 1990s, and it may be to the advantage of late entrants to plan investment and marketing strategies after that process is complete.

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Effects of Phytoplankton Blooms on Salmon Aquaculture in Puget Sound, Washington: Initial Research

John E. Rensel,[1] Rita A. Horner,[2] and James R. Postel[3]

Introduction

Marine salmon farming throughout the world is expanding rapidly. The production of net-pen reared Atlantic salmon, *Salmo salar*, leads the expansion because this species commands a high market value and is especially adaptable to culture conditions. Expansion of Washington State salmon net-pen operations has slowly increased since 1970 with 14 private sites operating as of late 1988.

In the early days of Washington State net-pen culture (1970–1975), losses of salmon were caused primarily by bacterial diseases, poor siting practices, and phytoplankton blooms. The first two problems have been lessened through the development of effective vaccines and the move to deeper areas with stronger currents.

Phytoplankton problems, however, persist and there has been no concerted effort to document or resolve them. In marine waters of western Washington, some net-pen systems have been removed due to phytoplankton-induced losses of salmon. In 1987, phytoplankton blooms in Washington were involved in the mortality of at least 250,000 Atlantic and Pacific salmon of all ages with monetary losses over $0.5 million. Fish-farming industry officials in Washington State presently consider this problem to be their number one research need.

Besides threatening the current production of approximately 9,000 tons of Atlantic salmon per year in Washington State, the problem hampers expansion of the industry because it compounds the risks related to site development. Some private growers hesitate to consider new sites because the costs of permit acquisition are high and untested sites may have unknown phytoplankton problems.

[1]School of Fisheries (WH-10), University of Washington, Seattle, Washington 98195.

[2]4211 N.E. 88th St., Seattle, Washington 98115.

[3]School of Oceanography (WB-10), University of Washington, Seattle, Washington 98195.